



DRYING SPRUCE-PINE-FIR LUMBER

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Lodgepole pine

Jack pine

White Spruce

Black spruce

Red spruce

Balsam fir

Alemann-spruce

Subalpine fir

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Acknowledgement

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DRYING SPRUCE-PINE-FIR LUMBER

SUMMARY

This manual is intended to serve as an educational resource and working tool for people actively involved in the drying of Spruce-Pine-Fir (SPF) lumber. The manual covers subject matter from the basic principles of drying through to the application of techniques specific to the drying of this species group. The range and depth of information presented has been selected to meet these objectives.

A great deal of attention is given to the diversity of material within the SPF grouping and how that impacts on decisions made concerning drying. The authors have tried to present solutions to cover a wide range of resource and operating conditions. The early chapters in this manual are intended to provide readers with the background they need to analyze the various potential solutions with regard to their own situation.

Studies conducted at our laboratories have provided a lot of the background for the material in this manual. Detailed results of testing conducted at FPInnovations – Forintek Division on the drying of SPF can be obtained from the technical reports listed under Further Reading.

Lumber drying should not be considered just as the actions that take place in the kiln or the air drying yard. One of the objectives of this manual is to demonstrate how the kiln operator must maintain a wide field of view when managing the drying process. Joseph M. Juran, a quality management pioneer, described a process as "*...a systematic series of actions directed to the achievement of a goal. Process performance and excess variation will directly affect an organization's financial performance.*" The objective is not to eliminate all variation but to understand it and minimize its impact on the operation's performance.

"Variation in a process is natural; it should be expected. But it is a wild beast that must be controlled." (Gitlow and Gillow from The Deming Guide to Quality and Competitive Position.)

ACKNOWLEDGEMENTS

This manual includes results and references to many studies on the drying of SPF that have been conducted at FPInnovations - Forintek Division. A selection of those studies has been listed in Appendix VIII, Further Reading. This manual would not have been possible without the efforts of all of the members of Forintek's National Drying Group and the authors thank them.



NOTE TO READERS

As a neutral organization, FPInnovations – Forintek will not recommend one brand of equipment over another. Our goal is to provide information that will help industry make the best choices for their particular situation and to make the best use of their equipment.

Information provided in this manual must be applied in consideration of many site-specific factors. This includes recommendations with regard to drying schedules and equipment selection. Wherever possible, the range of site-specific factors to be considered are listed and mill operators must review these to determine which ones are relevant to their situation.

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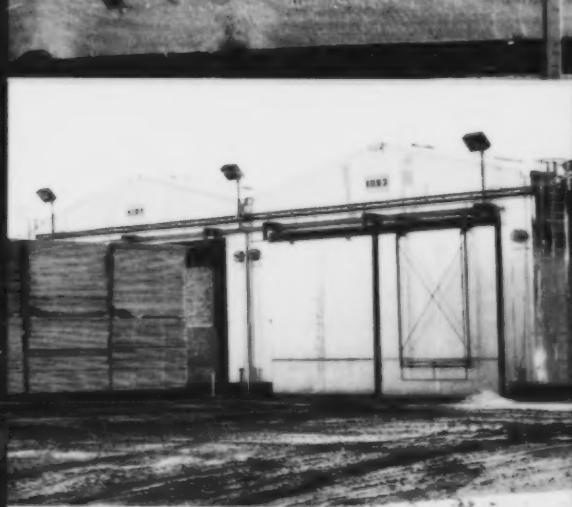
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COST CONSIDERATIONS IN DRYING

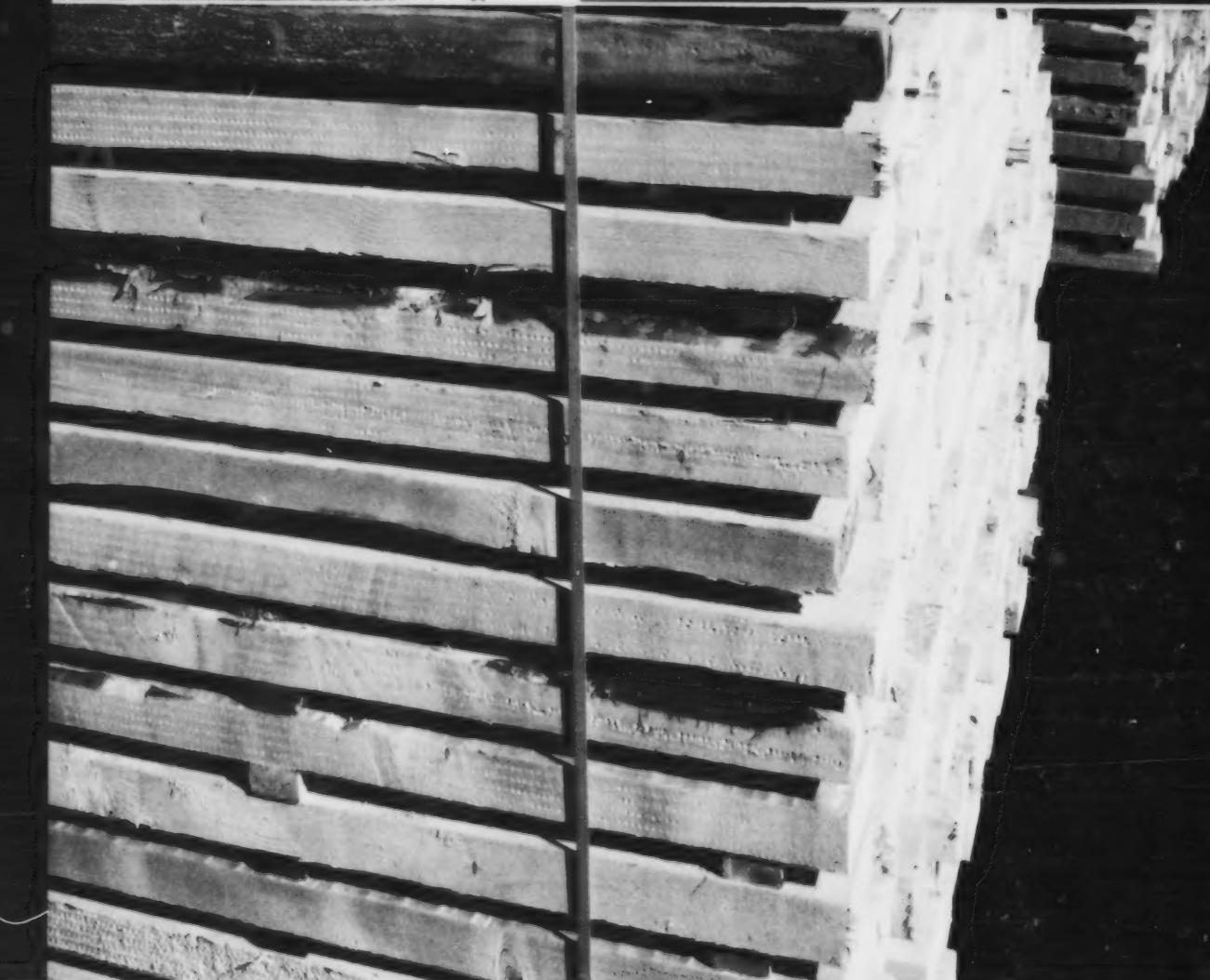
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DRYING SPRUCE-PINE-FIR LUMBER



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WHITE SPRUCE
Picea glauca (Moench) Voss



ENGELMANN SPRUCE
Picea engelmannii Parry ex Engelm.



BLACK SPRUCE
Picea Mariana (Mill.) BSP.



RED SPRUCE
Picea rubens Sarg.



LODGEPOLE PINE
Pinus contorta Dougl.



JACK PINE
Pinus banksiana Lamb.



SUBALPINE FIR
Abies lasiocarpa (Hook.) Nutt.



BALSAM FIR
Abies balsamea (L.) Mill.

SPF GROWING REGIONS, SPECIES DIVERSITY, AND GENERAL DRYING PROPERTIES

1.1 THE SPF GROUPING

In Canada the SPF or Spruce-Pine-Fir species grouping includes eight species as defined within the National Lumber Grades Authority (NLGA) "Standard Grading Rules for Canadian Lumber". The common names in English and French are listed in Table 1-1 along with the scientific names for each. These eight species have been grouped together for processing and marketing as their properties are similar and their growing regions overlap. In most regions of the country, mills processing this species mix are dealing with at least 3 or 4 species from this grouping. This manual will deal with the issues of drying these species - mixed as well as individually.

Of these eight species, four can be considered as national in their range. White and black spruce, jack pine and balsam fir can be found from the east coast westward all the way to the Rockies and from the southern border all the way to the northern limit of tree growth. The remaining four species have a limited regional distribution but are predominant species within their ranges. Red spruce is found mainly in the Maritime provinces and Quebec. Lodgepole pine is found throughout British Columbia and the western portion of Alberta. Engelmann spruce and subalpine fir are found in the interior of British Columbia and into the foothills of Alberta.

As a result of the number of different species involved and the overlapping of ranges most mills are processing their own unique blend of material. This is one of the challenges of preparing drying information for this species mix.

Table 1-1

Species that comprise the Spruce-Pine-Fir (SPF) species grouping as defined within the National Lumber Grades Authority (NLGA) "Standard Grading Rules for Canadian Lumber"

Common Name (English)	Common Name (French)	Scientific Name
White spruce	Épinette blanche	<i>Picea glauca</i> (Moench) Voss
Engelmann spruce	Épinette d'Engelmann	<i>Picea engelmannii</i> Parry ex Engelm.
Black spruce	Épinette noire	<i>Picea Mariana</i> (Mill.) BSP
Red spruce	Épinette rouge	<i>Picea rubens</i> Sarg.
Lodgepole pine	Pin tordu latifolié	<i>Pinus contorta</i> Dougl.
Jack pine	Pin gris	<i>Pinus banksiana</i> Lamb.
Subalpine fir	Sapin subalpin	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Balsam fir	Sapin baumier	<i>Abies balsamea</i> (L.) Mill.

1.2 RAW MATERIAL DIVERSITY

The physical properties related to drying are discussed in Chapter 2, however, there are a number of other factors that have a potential impact on drying. Since some of these species grow across a wide geographic range, they exhibit a certain amount of within-species variability. Some of this variability is likely due to slight genetic differences in trees of the same species separated by a large geographic distance. Other variability may be more related to local growth conditions. For example, material growing in low, swampy areas tends to be slower grown than material originating from higher, well-drained sites. A tremendous range in growth rate and log size and form can be seen in material from within the same growing region (see Figure 1-1).

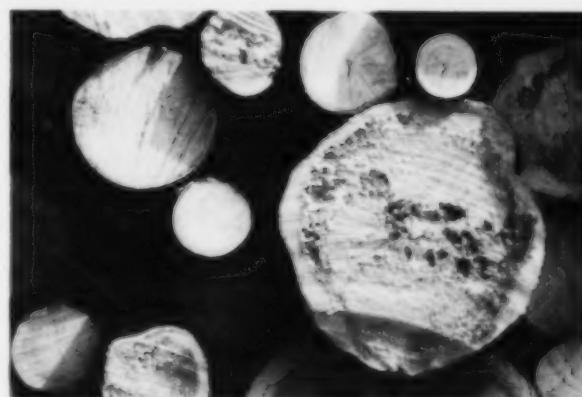


Figure 1-1

Diversity within the SPF group as evidenced by the range of log sizes processed at one mill.

1.3 GENERAL DRYING CHARACTERISTICS OF INDIVIDUAL SPECIES

1.3.1 WHITE SPRUCE

White spruce is typically cut and processed with other spruce species such as red spruce in the Maritimes and Engelmann spruce in B.C. On its own, it can be dried on relatively aggressive schedules with good results. It commonly grows in the same area as balsam fir and is therefore often mixed with this species for processing. Drying these two species together poses a problem, as balsam fir will typically take 2 to 3 times as long to dry. If dried together, compromises must be made that usually result in either over-dried spruce, with extra drying degrade, or a high percentage of wet balsam fir. Some difficulties may arise when drying white spruce with denser, slower-drying black spruce. This is usually accounted for in the drying schedule rather than by segregating these species.

Warp is the main drying defect of concern for white spruce. As with any of the spruce species, it is prone to reaction wood (not as prevalent as in black spruce). This wood fibre shrinks considerably more in the longitudinal direction than normal wood and contributes to increased levels of crook, bow and twist. Cupping is also a concern, especially in wider boards, due to the large differential between radial and tangential shrinkage. Final moisture content uniformity is always a concern when drying any spruce species including white spruce. This is due to the variability in initial moisture content (MC) and variations in density within this species. Collapse can occur in white spruce due to the relatively low density and high initial moisture content of the sapwood. Problems can be severe when drying with harsh initial conditions such as a high-temperature schedule. Collapse can usually be avoided by maintaining high humidity for the first stage of drying.

1.3.2 ENGELMANN SPRUCE

Engelmann spruce is native to the southern interior region of B.C. White spruce also grows throughout this region and the two species are often indistinguishable. As with the tree, the wood is also very similar in terms of specific gravity, initial MC levels and drying characteristics. The two species are not separated or even distinguishable for drying. Comments listed in the previous section on white spruce are therefore relevant to Engelmann spruce.

1.3.3 BLACK SPRUCE

Black spruce is typically cut and processed with jack pine, balsam fir and other spruce species. In many northern

areas it is the dominant species and dictates the drying conditions when these species are dried together. Most of the production has historically gone into construction grade lumber with a final MC requirement of 19% or less. Due to its good strength properties, black spruce is also used extensively for MSR (machine stress rated) lumber, where a slightly lower final MC is often targeted. The small tree size and variability in wood properties contribute to final MC variation and extra drying defects. If the intended end use is some form of specialty product, gentler drying schedules can be employed to enhance the uniformity of final MC and to minimize drying defects.

Black spruce is prone to a number of drying defects, mostly resulting from a wide range of physical properties as well as various growth-related characteristics. Warp is a major problem with this species. The frequent presence of reaction wood and cross grain are definite contributing factors to a higher incidence of crook, bow and twist. Final MC variability aggravates the problem further due to the effect of over-drying the faster-drying material in each kiln load. Due to the relatively small log size and the difference between radial and tangential shrinkage, cupping will be a problem with wider boards (especially when dried to low MCs).

1.3.3.1 YELLOW SPRUCE

In some regions of the country, particularly in Northern Quebec, a portion of the black spruce population has been identified as being particularly difficult to dry. It is known locally as "yellow spruce" ("épinette jaune") due to the yellowish hue often seen on kiln-dried boards. Although there is no botanical distinction between this sub-group and "normal" black spruce, both the physical and drying attributes are quite different. Studies at Forintek have distinguished "yellow" spruce as being both denser and having a higher initial MC than "normal" black spruce. Specific information on these properties is presented in Chapter 3. Material identified as "yellow" spruce is more likely to originate from low lying swampy areas where the trees are typically very slow growing. Ring counts of up to 35 rings per inch were observed (average of 19 rings per inch) in yellow spruce from the Abitibi region of Quebec versus a more typical average value of 7 rings per inch for normal black spruce from the same region. Figure 1-2 shows a comparison of growth rate on board ends for "normal" versus "yellow" spruce samples. Information on how to deal with "yellow" spruce in order to minimize its impact on the drying operations is provided in Chapters 11 and 15.

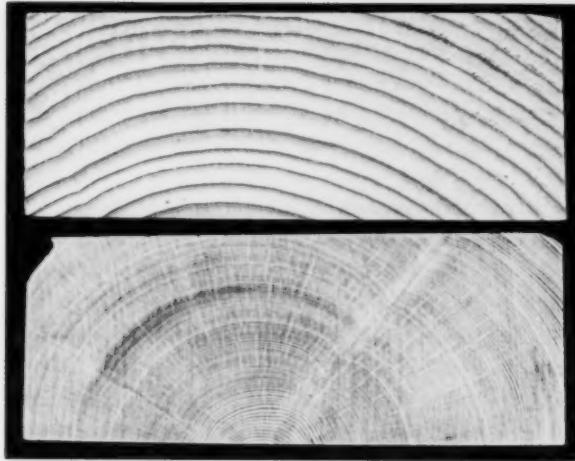


Figure 1-2

Photo of board ends showing difference in growth rate between yellow spruce and normal black spruce.

1.3.4 RED SPRUCE

Red spruce is found mostly in the Maritime region of Eastern Canada and is typically cut and processed with other spruce species from that region including white and black spruce. On its own, it can be dried on relatively aggressive schedules with good results. Drying times are similar to white spruce so mixing it with that species is not a concern. It commonly grows in the same area as balsam fir and is therefore often mixed with this species for processing. Drying these two species together poses a problem, as balsam fir will typically take 2 to 3 times as long to dry. Some difficulties may arise when drying red spruce with denser, slower drying, black spruce. This is usually accounted for in the drying schedule rather than by segregating these species.

Warp is the main drying defect of concern for red spruce. As with any of the spruce species, it is prone to reaction wood which will contribute to increased levels of crook, bow and twist. Cupping is also a concern, especially in wider boards, due to the large differential between radial and tangential shrinkage. Final MC uniformity is always a concern when drying any spruce species, including red spruce. This is due to the large variability in initial MC and variations in density within this species. Collapse can occur in red spruce, especially when drying high initial-MC boards with harsh drying conditions such as a high-temperature schedule. This can usually be avoided by maintaining high humidity for the first stage of drying.

1.3.5 LODGEPOLE PINE

Lodgepole pine is usually sawn and dried for structural lumber but is increasingly used for other, higher-valued products. This species is usually harvested and processed in mixture with white spruce in Western Canada and, depending on the region, varying proportions of subalpine fir or balsam fir. When dried with white spruce it is the spruce that dries faster and to a lower final MC than the lodgepole pine. Final MCs are more variable than with spruce, and wet pockets do occur. It can be high-temperature dried without causing undue degrade.

Lumber sawn from near the pith, particularly of small logs, has a tendency to twist. This species exhibits a wide range of log diameters and larger logs will produce larger dimension, higher grade boards. Upper grades are typically dried on much milder schedules to preserve quality and colour, and achieve a more uniform final MC.

1.3.6 JACK PINE

Jack pine is typically cut and processed with various spruce species and balsam fir. Due to its good treating and machining properties it is sometimes separated in the bush or sawmill and processed on its own. Jack pine tends to dry quite readily with good uniformity in final MC and few problems with downgrade. It will dry faster than either spruce or fir and as a result will tend to be over-dried when dried in mixed charges with these species. When dried on its own, more aggressive drying schedules, including high-temperature, can be employed and relatively good results obtained for construction grade lumber. If the intended end use is some form of specialty product, gentler drying schedules should be employed to enhance the uniformity of final MC and to minimize drying defects.

This species is not particularly prone to any of the major wood downgrading factors associated with drying. There is very little problem with reaction wood, which is a major factor in warp development in other softwood species. As a result, it can be over-dried without too much concern for increased warp. Due to the relatively small log size and the difference between radial and tangential shrinkage, cupping will be a problem with wider boards (especially when dried to low MCs). This species is not prone to problems with wet pockets or shake. When used in specialty products, such as siding and millwork, resin exudation can be a problem. This can generally be alleviated by using a kiln schedule with temperatures in excess of 82°C (180°F) for a portion of

the cycle. In general, this species is not as resinous as other pine species such as red and white pine.

1.3.7 SUBALPINE FIR

Subalpine fir has a relatively low specific gravity but its initial MCs for both sapwood and heartwood are high. Large variations in drying rate and initial MC make it a very difficult species to dry. Similar to balsam fir, it contains significant amounts of wetwood material which takes considerably longer to dry than normal wood of this species. The wetwood zones have a higher initial MC and dry at a slower rate than normal wood of this species. More information on dealing with wetwood is contained in Chapter 4.

When dried in mixture with spruce and pine, these two species will reach the target MC long before the subalpine fir. The faster drying material will be well over-dried and experience more shrinkage and warp if allowed to stay in the kiln until all the subalpine fir has reached the final target MC. Solutions for dealing with this material include pre-sorting, air drying, low-temperature drying, and post-sorting of "wets" for redrying. All of these options are discussed in later chapters.

1.3.8 BALSAM FIR

In most areas of the country balsam fir is not a dominant species and it is therefore normally harvested and processed with other SPF species. A few mills will separate this species in the bush or sawmill in order to sell it to the treated wood market or to alleviate drying related problems. Although it will take up preservative quite well, it does not dry as readily as other species from the SPF grouping. It is a difficult species to dry on its own but is even more difficult when mixed with spruce and/or pine. This species is prone to wet pockets which are the result of (or at least associated with) a bacterial infection in the standing tree. A description of wetwood and how to deal with it is presented in Chapter 4. Permeability between wetwood and normal wood is significantly different, to the extent that boards containing a high proportion of wetwood may take up to three times as long to dry as normal wood. There have been no drying technologies or methods to modify wood properties that have adequately addressed the problem of drying balsam fir. Techniques for dealing with species containing wetwood are presented in Chapter 4.

This species is prone to a number of drying related defects depending on the drying system employed and the severity of the drying schedule. A highly variable final MC is the main concern of most people drying or using this species. Localized wet pockets can remain at 50

to 60% MC or higher even after extended drying cycles. The variable final MC also results in a large proportion of over-dried lumber which, in turn, causes more down-grade due to warp. Twist and crook are the primary form of warp of concern for construction grade lumber. The low density and high initial MC of this species make it vulnerable to collapse, which can be quite severe when high-temperature drying schedules are employed. Internal checking is also a concern from the result of either steam explosions when drying aggressively or from high moisture gradients that remain at the end of most drying treatments.

1.4 SPECIES DIFFERENTIATION

Another complication in dealing with this species mix is identifying exactly what species are present. Distinction of the precise species within one genus is often difficult but in the case of spruce species is sometimes impossible. All of the species listed in this group can be readily identified in the tree form based on the form of the tree and characteristics of the bark and foliage. "Trees in Canada" by Farrar (1995) provides a good description of individual species.

Once the material has been processed to tree-length or log form it becomes a little more difficult to identify the species. Characteristics of the bark, i.e., texture and colour are the fastest and most commonly employed method of distinguishing species at this stage. Some mills will sort balsam or subalpine fir from their production at this stage either in the bush, the log yard or at the infeed to the sawmill debarking line. Visual characteristics of bark are also covered by Farrar.

Again it becomes more difficult to distinguish wood species after the material has been sawn. Wood colour, grain, as well as number and size of knots are all characteristics that can be used to make a visual sort. Some of these characteristics tend to change or modify in appearance as the wood dries and it is therefore best to become familiar with identification under a given set of lighting and wood moisture conditions. Some mills rely on making a visual sort of material at the sawmill. In some cases this may be for marketing purposes, for example separating Jack pine for pressure treatment, while in other cases it may be to facilitate drying such as removing balsam fir to dry it separately. Identifying the genus (spruce vs. fir vs. pine) is generally fairly accurate at this stage but distinction within a genus (white vs. black spruce) is very difficult, if not impossible based on gross characteristics of the wood. Examination with a hand lens or microscope can, in most cases, provide a definitive determination of species. Difficulty arises within the

spruce species where even microscopic examination cannot always determine with certainty the true species.

This confusion or inability to differentiate between species would not be an issue if it were not for the fact that some of these species have vastly different drying properties making it desirable, in some cases, to separate them before drying. Despite the difficulties mentioned above, some mills still rely on a visual separation of material along the green chain. The accuracy of this process varies considerably from mill to mill.

A number of different technologies have been investigated for on-line, automatic separation of species. This has included imaging techniques, analysis of air samples taken from close to the board surface and chemical indicators. To date the only technique that has been applied industrially has been the use of chemical indicators. The technology was developed and tested by Forintek and is now licensed to an equipment manufacturer and sold

under the name "Spruce and Fir Drying Optimizer". As the name implies, it is designed primarily to handle a separation between spruce and balsam fir. A chemical reagent (Saptek[®]) is sprayed on the board ends and produces a colour change as shown in Figure 1-3.

Whether species separation is done in the bush, mill yard or at the green chain there are definite advantages to be realized in the drying operations. As discussed in the previous sections, there are distinct differences in the drying properties of the different species within the SPF grouping. The lumber industry has been implementing measures to become more efficient, and at the same time is under pressure to produce a higher-quality, more consistent end product. Both of these demands can be furthered by supplying a more uniform initial product to the kilns. Species separation is one means of achieving this but other pre-sorting options exist which can be used instead of, or in conjunction with, species sorting. Pre-sorting is discussed in more detail in Chapter 11.

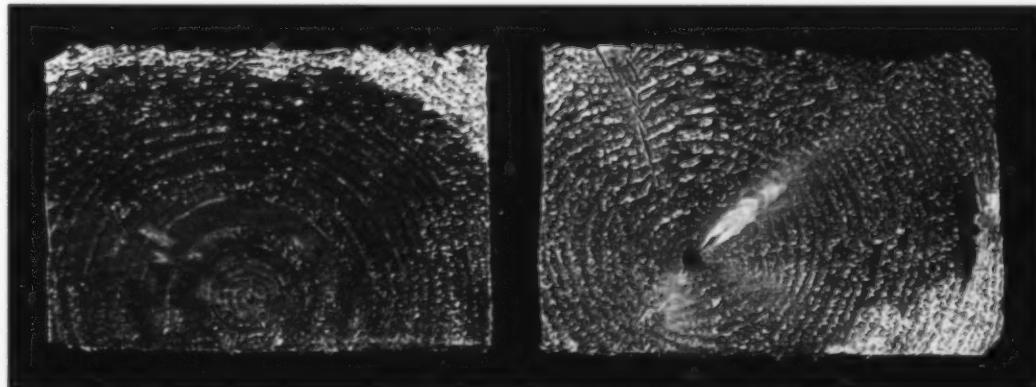


Figure 1-3

A commercial species sorting system applies a chemical reagent (Saptek[®]) that produces a colour change as shown above for balsam fir on the left versus spruce on the right.



WOOD STRUCTURE RELATED TO DRYING

2.1 INTRODUCTION

A comprehensive knowledge of the characteristics of any material is essential to its best utilization. This is especially true for wood because of its cellular nature and its complex cell-wall structure. One of the greatest architects of all time, Frank Lloyd Wright, put it best in 1928: "We may use wood with intelligence only if we understand wood". Kiln operators and quality control staff who wish to be successful in their trade need to understand not only the principles of tree growth and wood structure, but also the normal and abnormal variation in wood properties.

Although we are surrounded by wooden structures, wooden objects and at least 5000 kinds of wood products if paper is included, the essential nature of wood escapes us because our eyes cannot see the structural detail. In other words, the structure of wood is much too fine to see. Unaided, the human eye cannot separate

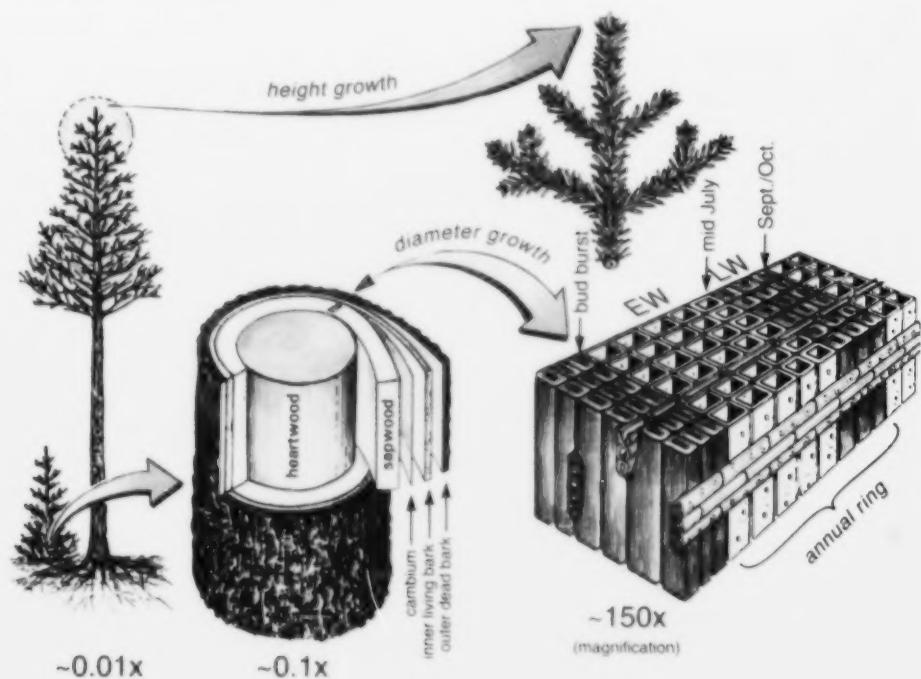
two point objects which are closer together than about 0.1 mm; this is our limit of resolution. It so happens that about three to five wood fibres could be put side by side in a 0.1 mm wide space. For this reason, a microscope is required for studying wood structure. In this chapter, softwood structure will be discussed at various magnifications, from 200 to 5000 times, by "calling-up" a few simple props like milk-shake straws and pipes. The normal and abnormal variation in structural detail will be linked to drying and drying degrade.

2.2 TREE GROWTH AND WOOD ANATOMY

A tree stem in cross section reveals the secrets of tree growth and wood anatomy. Figure 2-1 shows the readily visible layers of tissue, the most obvious being the wood portion with concentric annual rings. Equally obvious is the bark tissue, composed of two layers: The inner living bark and the outer dead bark. The inner living bark is

Figure 2-1

Depiction of, and interaction between, the various components of a tree and woody tissue viewed at different levels of magnification.



comprised of conducting and storage cells for the "fuel" (simple sugars produced through photosynthesis) that runs the total tree system.

Perhaps the least obvious but the most important layer of tissue in the cross section is the cambium. It is a thin layer of cells, located between the inner bark and the wood, as shown in Figure 2-1. This is where both wood and bark fibres are produced by the tree through cell division, using energy derived from the products of photosynthesis. Wood fibres are formed in an aqueous environment, and exist in a living tree in the "green" or maximum swollen state.

Annual rings seen in the cross section are a chart of yearly growing activity, which lasts approximately 4.5 months of the year. Active cambial division (i.e., tree growth) begins at the time of flushing, usually in mid-May to mid-June, when buds break their scales and reveal their needles. Low-density earlywood (springwood) is produced from this time until about mid-July, when leader growth stops and the maturation of fresh new needles takes place. At this time new foliage ceases to be a net sink of photosynthate and becomes an exporter. Concurrently, there is a reduction in cambial division, therefore, more material becomes available for fibre wall thickening. Reduced crown activity limits growth-regulating hormone production, which helps the formation of high-density latewood. Generally darker in appearance, latewood continues to be produced to the end of the growing season, at about late September, when lower temperatures and a reduced photoperiod bring on tree dormancy. In summary, from bud-burst to mid-July the growing tree forms large diameter thin-walled fibres called earlywood, and during the latter part of the growing season the tree forms small diameter thick-walled fibres called latewood. Together, these thin- and thick-walled fibres form an annual ring, or more popularly, a tree ring (Figure 2-1).

Often visible in a stem cross section is the different coloration of two broader divisions, sapwood and heartwood. The sapwood portion of the tree is physiologically active and is in continuous communication with the cambium and the inner living bark. Sapwood transports sap from the fine root hairs through the root system, the stem and the branches to the needles (leaves) in the crown. The sapwood acts as a food and water storage reservoir as well. Heartwood can be found usually at the centre of mature stems, and it is usually darker in colour than the sapwood, because of organic deposits (extractives). At one time heartwood was sapwood, but it no longer functions physiologically, its cells are dead. Sapwood

contains up to four times more water than heartwood (see Table 3-1). In spite of this, it is normally more difficult to remove water from heartwood than sapwood.

2.3 MICROSCOPIC STRUCTURE OF WOOD

2.3.1 OVERVIEW OF MICROSTRUCTURE

At 200-times magnification one can think of wood as a handful of milkshake straws held so tightly together that there would be no air spaces left between the straws, only on the inside. At this magnification one complete softwood fibre would be about 7 mm in diameter and about 700 mm long (generally, in softwoods, fibre length equals 100 times fibre diameter). One could easily make an authentic fibre model by pushing together four milkshake straws end-to-end.

A typical 8-foot 2x4 contains about 2.5 billion fibres arranged side by side and aligned along the long axis. Due to the geometry of most wood products, such as this 2x4, moisture movement inevitably occurs across the grain. In moving moisture from the core to the surface the water molecules must pass through many cell walls and pit openings. Therefore, the condition of the pit openings and the thickness of the cell walls (wood density) have a significant impact on drying rate.

Wood is an anisotropic material, which means that it has different properties when viewed in different directions. Because of the arrangement of growth rings in the tree, as well as the horizontal and vertical orientation of the individual cells, it is appropriate to consider the structure of wood in three-dimensional terms. Therefore, normally wood is examined in three planes: cross (transverse), tangential (flat grain) and radial (edge grain). This concept is illustrated in Figure 2-2 at various magnifications. The top surface of this small cube (and a short length of 2x6 lumber) represents the cross-sectional surface, the left-hand front surface is the flat grain (tangential plane), and the right-hand front surface corresponds to the edge grain (radial plane). About 95 percent of the volume of wood is occupied by fibres which are oriented in the vertical direction. The remainder is mostly horizontally aligned ray tissue, although some species also have a small percentage of epithelial cells which form resin canals.

2.3.2 BORDERED PITS AND THEIR IMPACT ON DRYING

Figure 2-2 also shows two individual fibres and a few ray cells to bring to attention the morphology of these elements. These examples show that the thick-walled latewood fibres have very few markings, whereas the large-diameter, thin-walled earlywood fibres have a lot

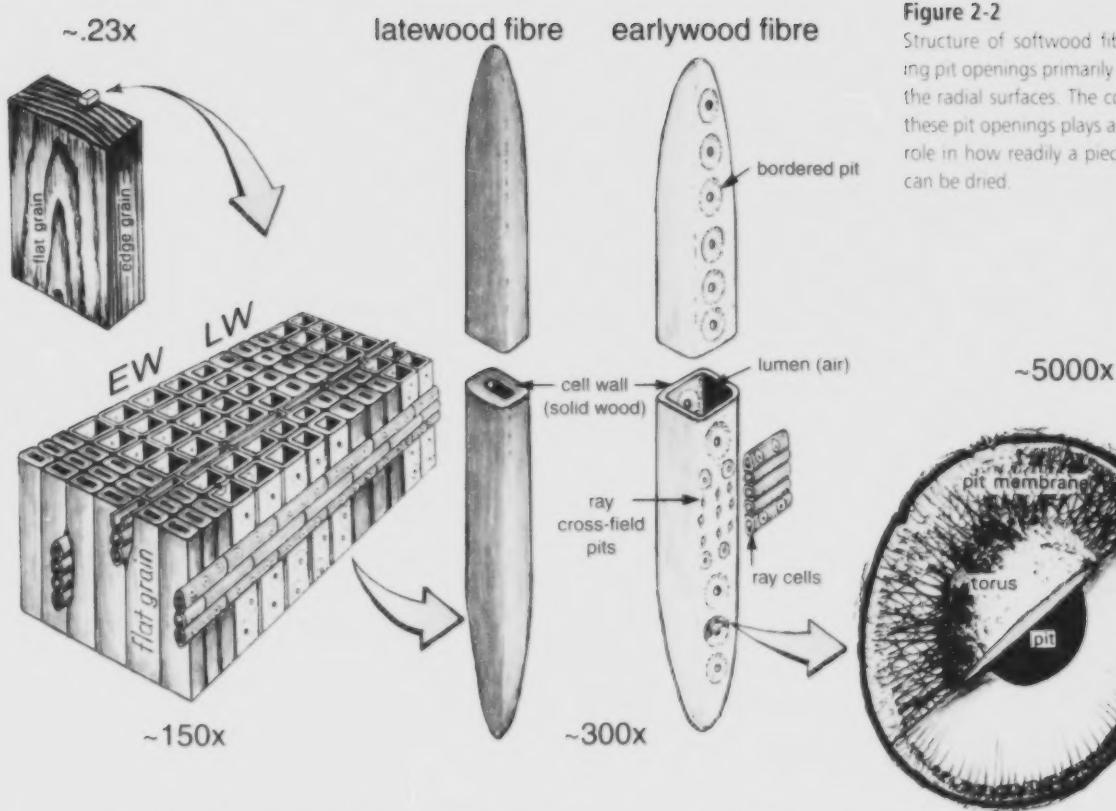


Figure 2-2
Structure of softwood fibres showing pit openings primarily located on the radial surfaces. The condition of these pit openings plays a significant role in how readily a piece of wood can be dried.

of markings, but only on the radial surfaces, in forms of bordered pits and ray cross-field pits. Pits are perforations through the fibre wall. If unblocked, sap (water or other fluids and gases) can flow through from one fibre to another. The pitting occurs almost exclusively on the radial face of the fibre wall. The more frequent pitting in earlywood fibres is due to the greater degree of physiological activity taking place when the earlywood fibres were formed.

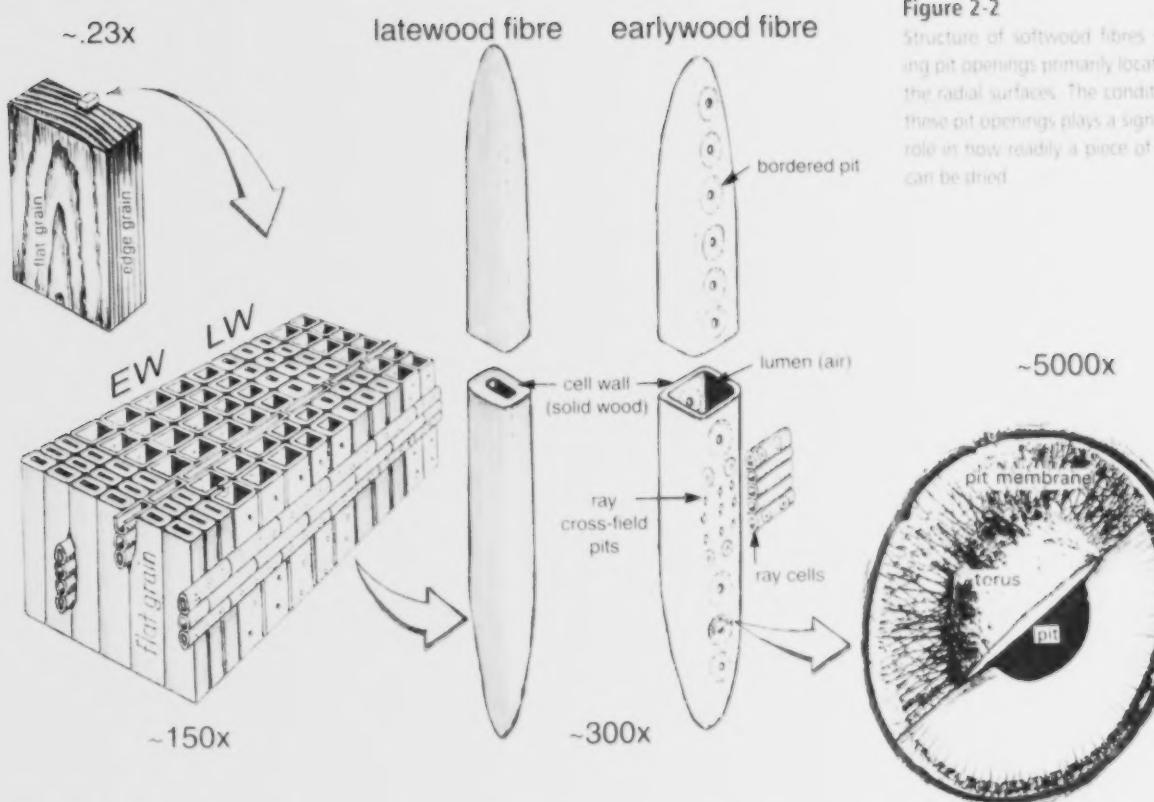
On average each earlywood fibre has about 5 to 10 ray contact areas along its length and about 100 bordered pits. The shape and size of ray cross-field pits contained in these areas provide vital diagnostic clues in microscopic species identification.

A bordered pit in one fibre usually occurs opposite another one in an adjacent fibre, forming a pit pair, a fibre-to-fibre communication link. The pit pairs are actually holes in the fibre wall, a short distance apart, forming a pit chamber which is separated by a sieve-like pit membrane and a torus.

The torus is the thickened part of the sieve-like membrane that acts as a valve. When the torus is in a central (open) position, sap or other liquids can bypass it and

flow freely through the sieve-like pit membrane. This situation in sapwood makes the wood very permeable. It allows the sapwood to dry easily and to be pressure-treated with wood preservatives. Usually when sapwood becomes heartwood the valve (torus) will move to one side or the other in the pit chamber, thus sealing the pit. This plugs up the passageways, making the heartwood impermeable. This is one reason why the heartwood of most softwoods is usually more difficult to dry (especially above the fibre saturation point) and to impregnate with preservatives than the sapwood.

The practical implications of these anatomical features include the paintability and the dryability of wood. More precisely, paint sticks better to the radial surface (edge grain) than to the tangential surface (flat grain), because paint has a better chance to penetrate the wood through the bordered pit apertures. For this reason paint adhesion is not very good in the latewood zone (or on the flat grain) where pitting is infrequent. Interestingly, wet-wood dries faster on the flat grain than on edge grain. At first this seems like a contradiction, however, it must be kept in mind that paint penetration is very shallow, while moisture movement during drying is deep to the centre of the piece. In lumber drying the ray cells can act as conduits for moisture movement.



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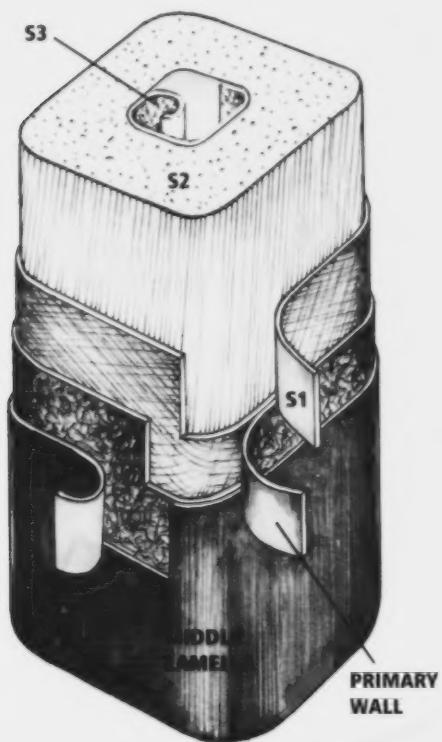
2.3.3 MICROFIBRIL ORIENTATION

A higher magnification is required to illustrate fibre wall architecture and show how microscopic structural detail has macroscopic implications. Solid wood-substance, or cell-wall material, is made up of precisely aligned organic building blocks, comprised of 45% cellulose, 27% hemicellulose and 28% lignin.

Figure 2-3 shows at high magnification the layered structure of the fibre wall. Included here is the lignin-rich middle lamella (ML), a layer of "glue" that holds individual fibres together in a piece of wood. (This "glue" is the target of the chemical pulping process—dissolving the ML causes the wood to separate into its individual fibre elements forming pulp.) The lignin imparts the brown color to wood and also its stiffness. Without lignin the wood is pure cellulose, white in colour, and as flexible as rubber.

Figure 2-3

The fibril orientation for normal mature wood versus that for juvenile and compression wood as shown in Figure 2-4.



The primary wall (P) is made up of a loose and random weaving of cellulosic microfibrils intermixed with lignin. In the secondary wall, made up of S1, S2, and S3 layers, these cellulosic microfibrils are closely packed. The S2 layer is the thickest of the three and, as a result, has the greatest impact on how the fibre will perform in strength tests, and in shrinking or swelling. Particularly important is the orientation or angle of the microfibrils in this S2 layer. Microfibril angle refers to the mean helical (spiral) angle that the fibrils of the S2 layer of the fibre wall make with the longitudinal axis of the fibre.

Microfibril angle has macro implications due to the anisotropic (has physical properties which depend on direction) nature of wood. As wood absorbs or releases water it swells and shrinks more in the tangential direction than radially. Shrinkage of the fibre wall, and therefore of the whole wood, occurs as bound-water molecules escape from spaces between cellulose microfibrils allowing these cellulose microfibrils to move closer together. The amount of shrinkage that occurs is generally proportional to the amount of water that is removed from the wood and the orientation of microfibrils in the cell wall. Swelling is simply the reverse of this process.

Figure 2-3 shows the fibril orientation for normal mature wood versus that for juvenile and compression wood as shown in Figure 2-4. The longitudinal shrinkage of normal mature wood is negligible for most practical purposes, because in normal wood the microfibril orientation is about 7° off the cell axis. Usually, some longitudinal shrinkage does occur in drying from green to oven-dry condition, but this is only 0.1 to 0.2% for most species and rarely exceeds 0.4%. As an example, an 8-foot long stud for the wall of a house would shrink approximately 0.1 to 0.2 in. (2 to 5 mm) in length when drying from green (>30% MC) to oven-dry condition (if it were cut from normal wood). If this stud were cut from compression wood or juvenile wood, where microfibril orientation could be up to 45°, then the longitudinal shrinkage can be as much as ten-fold (1.0 to 2.0 in. or 2.5 to 5.0 cm) as a result. Troublesome warping results when longitudinal shrinkage potential varies within a piece of wood due to the presence of normal mature wood in combination with juvenile wood or compression wood. The development of warp is discussed in more detail in the next chapter.

2.3.4 JUVENILE WOOD

Juvenile wood has been characterised for a number of softwood species through microfibril orientation and longitudinal shrinkage measurements. The results show

that microfibril orientation near the pith is greater than 35° with a gradual decrease as a function of age. Pith-to-bark longitudinal shrinkage measurements show similar trends with excessive shrinkage of 1 to 2% near the pith compared to 0.3% or less by age 20. These large fibril angles in juvenile wood have been correlated to lower strength and stiffness in lumber products where these lower values could not be attributed to appreciable differences in density.

2.3.5 COMPRESSION WOOD

Compression wood is a term applied to abnormal wood formed in softwood tree stems and branches that have grown out of the vertical position. As a rule, compression wood is formed in softwoods on the underside (or compression side) of leaning stems. This name refers only to the position where compression wood is formed and does not imply that it forms as a result of compression stress.

The two main disadvantages of compression wood to the wood worker are its deleterious effects on strength and shrinkage. Brash failures (abnormal failures across the grain) in loaded wooden members may often be traced to the presence of compression wood. In structural uses where load bearing capability is vital, such as ladder rails, avoidance of compression wood is essential to prevent breakage at lower than expected loads. Excessive warping can often be traced to compression wood because it shrinks 10- to 20-times more than normal wood.

2.4 SUMMARY

This brief discussion was intended to introduce some factors that will influence water transport in wood and therefore affect the overall industrial drying process. An understanding of the wood structure features and how they affect water movement is extremely important when designing drying schedules. Many of the wood features and characteristics described in this chapter will be used to explain certain wood drying behaviors or the need for various approaches when drying.

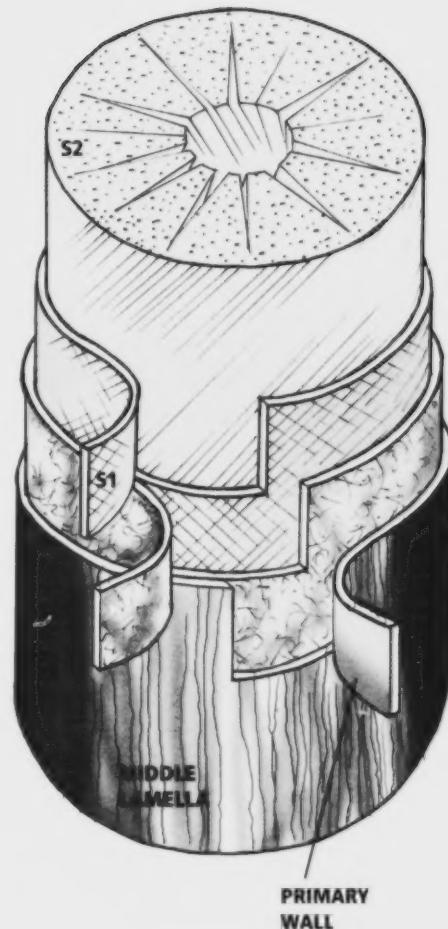


Figure 2-4

A softwood fibre originating from a compression wood zone. The microfibril angle in this case is not parallel to the length of the cell and when compaction of these microfibrils (shrinkage) occurs the cell will be reduced significantly in length, as well as thickness.

NOTES

WOOD MOISTURE RELATIONS

3.1 MOISTURE IN WOOD

Wood in its natural state always contains a substantial amount of water, the amount varying from tree to tree, log to log and board to board. Variations in the amount of water in boards sawn from the same log are due mainly to the position in the log from which the boards were sawn. In many softwood species the sapwood is very much wetter than the heartwood. Therefore, boards of the same size sawn from these two locations will contain different amounts of water and sapwood boards will weigh more than heartwood boards.

Moisture in wood occurs in two distinct forms:

1. as free water in cell cavities that can be in the liquid or vapour state;
2. as bound water absorbed within and bonded to the cell wall structure.

As the name implies "free water" is not attached or bonded to the wood. It exists as liquid (or frozen) water and water vapour within cell cavities. Free water at or near the surface can be readily evaporated and driven out of the wood. Free water toward the core of a board must be moved through the wood structure before it can be evaporated at the wood surface. Movement of free water is limited by the pathways available through the wood. In general terms, movement and release of free water from wood happens at a much greater rate than movement and release of bound water. Water vapour is a form of free water but accounts for only a small proportion of the total amount of water present in green or partially dry wood.

Bound water refers to water molecules that are chemically bonded to the wood structure. Breaking any chemical bond requires energy, which in the case of most wood drying processes is provided by heat. Bound water is typically the last portion of the water to be removed from wood and happens at a much slower rate than removal of free water. Throughout most of the drying

process wood contains varying amounts of free water and bound water. For example, near the mid-stage of a softwood drying cycle, boards will contain strictly bound water near the surface and a mixture of bound and free water in the core. Mechanisms of moisture movement are discussed in more detail in Chapter 6.

3.1.1 DEFINITION OF MOISTURE CONTENT

The moisture content (MC) in a sample of wood is defined as the weight of water in the wood expressed as a percentage of the weight of the oven-dry wood. It can be calculated as the difference between the initial (wet) weight and the oven-dry weight, divided by the oven-dry weight and multiplied by 100 percent.

$$\text{Moisture Content (\%)} = \frac{(\text{Initial Weight}^1 - \text{Oven-dry Weight})}{\text{Oven-dry Weight}} \times 100$$

Initial weight = Weight of wood at the time the sample is obtained.

For example, the moisture content of a sample of wood which weighs 40 grams when wet and 30 grams after oven-drying is calculated as follows:

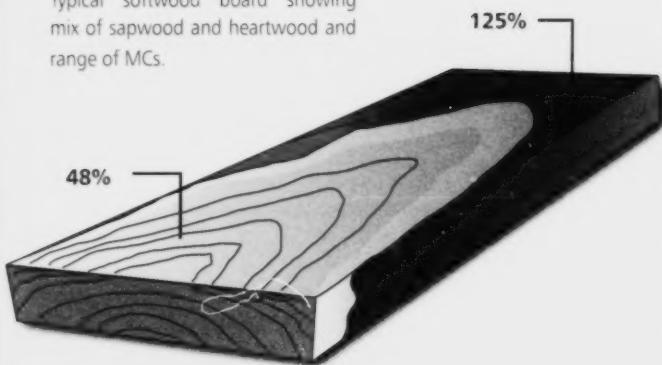
$$\text{Moisture Content (\%)} = \frac{(40 - 30)}{30} \times 100 = 33.3\%$$

3.1.2 TYPICAL GREEN MOISTURE CONTENT VALUES FOR SPF

Average green MCs for commercially important SPF species are shown in Table 3-1. These values represent MC in the material measured "fresh off the stump" and as close as possible to the natural condition of the living tree. The values for sapwood and heartwood represent the MC of a board containing strictly one or the other of these wood types. Given the relatively small log size of most SPF species, it is not realistic to expect to find boards that are either 100% sapwood or 100% heartwood. Therefore, MC even in very fresh material will vary depending on the proportion of sapwood and heartwood in a board. Additionally, MC will vary along the length of a board as the proportion of heartwood

Fig 3-1

Typical softwood board showing mix of sapwood and heartwood and range of MCs.



to sapwood changes. Figure 3-1 shows a board with varying amounts of sapwood along the length and the impact on average MC at various positions.

Green MC is even more variable when assessed in green lumber at the sawmill or prior to drying. A number of factors will influence the results of MC testing conducted at these points in the process, including:

- storage time of logs or treelengths in the bush;
- storage time and conditions at the sawmill logyard;
- outside influences such as insect infestation of the standing timber and forest fires; and
- duration of storage of green lumber and environmental conditions in the yard prior to drying.

Table 3-2 lists some typical average MC values obtained from lumber samples collected at sawmills in various regions of the country. Rather than listing MC values for sapwood and heartwood, minimum and maximum observed values are listed. It is intuitive that the wide range of initial MC values listed here will contribute to a wide range of drying times.

Table 3-1

Green MC (% of oven-dry weight) for sapwood and heartwood and overall species average based on relative proportion of sapwood and heartwood.

	Species	Moisture Content		
		Heartwood	Sapwood	Average
East	Black spruce	52	113	77
	"Yellow"(black) spruce	n/a	n/a	74
	Red spruce	41	132	89
	Jack pine	33	124	51
	Balsam fir	88	173	118
West	White spruce	38	144	55
	Engelmann spruce	59	169	64
	Lodgepole pine	38	115	50
	Subalpine fir	56	153	65

Table 3-2

Typical MC levels as measured in green lumber sampled at various Canadian commercial sawmill operations.

Species and Location	% Moisture Content (Oven-dry basis)			
	Average	Standard Deviation	Maximum Value	Minimum Value
Black spruce – Northern Quebec	44	12	100	26
"Yellow" (black) spruce	74	19	137	36
Jack pine – Northern Ontario	48	15	106	28
Balsam fir – Northern Quebec	114	34	207	41
Subalpine fir – B.C.	74	n.a.	200	30
Lodgepole pine – B.C.	61	n.a.	150	30
White spruce – B.C.	102	n.a.	255	30

3.2 WEIGHT OF WOOD

3.2.1 SPECIFIC GRAVITY

Specific gravity is a physical property of wood that is an indicator of the ease of drying as well as an index of weight (Table 3-3). In general, the heavier the wood, the slower the drying rate and the greater the likelihood of developing defects during drying. Specific gravity is defined as the ratio of the weight of a body to the weight of an equal volume of water. The specific gravity of wood is usually based on the volume of the wood at some specified moisture content and its weight when oven-dry:

$$\text{Specific Gravity} = \frac{\text{Oven-dry Weight of Wood}}{\text{Weight of Equal Volume of Water}}$$

As with most properties of wood, the specific gravity can vary significantly within a species. Since specific gravity can impact drying rate, these variations in specific gravity within a species can partly explain differences in final MC among pieces. Specific gravity values can be used to estimate the weight of wood in the oven-dry condition as well as at specific moisture levels as shown in the next section.

Table 3-3 Specific Gravity of SPF Species (based on green volume and oven-dry weight)

	Species	SG (Av)	SG (Range)
East	Black spruce	0.406	0.335 – 0.477
	"Yellow" (black) spruce	0.460	0.351 – 0.553
	Red spruce	0.380	0.333 – 0.427
	Jack pine	0.421	0.348 – 0.494
	Balsam fir	0.335	0.282 – 0.388
West	White spruce	0.354	0.283 – 0.425
	Engelmann spruce	0.375	0.312 – 0.438
	Lodgepole pine	0.403	0.333 – 0.473
	Subalpine fir	0.331	0.260 – 0.402

3.2.2 WOOD DENSITY AND WEIGHT DETERMINATION

If the specific gravity of a piece of green wood is 0.5, the oven-dry weight of one cubic foot of green wood is one-half the weight of a cubic foot of water. Since water weighs 62.4 pounds per cubic foot, a cubic foot of oven-dry wood with a specific gravity of 0.5 will have a weight or density of $62.4 \times 0.5 = 31.2$ lbs. The metric equivalent would be 1 cubic metre of water weighing 1000 kg multiplied by the specific gravity of 0.5 to give a density for oven-dry wood of 500 kg/m^3 .

The higher the specific gravity of wood, the greater the amount of wood per unit volume. Since MC is expressed as a percentage of the oven-dry weight, higher specific gravity species will contain more water than lower specific gravity species at the same oven-dry MC. The green weight of one cubic foot of wood can be calculated using the following formula:

$$\text{Green Weight} = \frac{\text{Specific Gravity} \times (\text{MC} (\%) + 100) \times 62.4}{100}$$

The metric equivalent would be:

$$\text{Green Weight (kg/m}^3\text{)} = \frac{\text{Specific Gravity} \times (\text{MC} (\%) + 100) \times 1000}{100}$$

For example, the green weight of one cubic foot of wood from a species with a specific gravity 0.4 at 75 percent MC is 43.7 lb (19.8 kg). The oven-dry weight (by substituting 0 for MC in the formula) is 25 lb (11.3 kg), and thus 18.7 lb (8.5 kg) of water are present. At a specific gravity of 0.6 and 75 percent MC, the green weight would now be 65.5 lb/ft³ (29.7 kg), the oven-dry weight would be 37.4 lb (17.0 kg), and the weight of water 28.1 lb (12.7 kg). Thus, although the MC value and wood volume is the same for both species, there is 9.4 lb (4.3 kg) more water in the species with the higher specific gravity.

The green weight of any volume of wood can be determined if the specific gravity and MC are known. It must be remembered, however, that the actual volume is usually quite different from the nominal volume. Therefore in order to get an accurate estimate of the wood weight, it is important to have accurate information on the lumber size.

3.2.3 BULK DENSITY AND BULK SPECIFIC GRAVITY

Green weight is the combined effect of both wood density and MC. As has already been mentioned, both of these properties can affect drying time. Therefore, it is useful to have a single value that expresses the effect of both of these properties in a manner that can be used to make valid comparisons among species. The green weight expressed in weight per unit volume can be referred to as the "bulk density". Bulk specific gravity is similar to specific gravity in that it does not have any units associated with it and can be calculated as follows:

$$\text{Bulk Specific Gravity} = \text{Specific Gravity} \times \left\{ \frac{(\text{Moisture Content} (\%) + 100)}{100} \right\}$$

As an example, a piece of black spruce with a specific gravity of 0.406 and a MC of 65% would have a bulk specific gravity of 0.670. To determine the bulk density follow the steps outlined in the previous section to determine wood weight per unit volume but substituting bulk specific gravity for specific gravity. Bulk density and specific gravity will be referred to in later sections when discussing factors affecting drying rate and options for pre-sorting material.

3.3 MOISTURE IN AIR

3.3.1 RELATIVE HUMIDITY

The most common term used to express the amount of water in air is relative humidity (RH). RH is defined as the ratio of the weight of water vapour present in a given volume of air to the weight of water vapour required to saturate that volume of air at the same temperature. The ratio is then multiplied by 100, so that RH is always expressed as a percentage. Air at a given temperature that contains the full amount of water that it is capable of holding has a RH of 100 percent and is said to be saturated. If the air is holding only half the amount that it is capable of holding, its RH will be 50 percent. If the temperature of a body of air is either increased or decreased, its moisture holding capacity will also be either increased or decreased. Therefore, if the temperature of a stream of air is increased, without adding more moisture to it, its relative humidity will be decreased. Similarly if the temperature of air is decreased, without adding or removing moisture, its relative humidity will be increased. Cooling air below the point at which it is saturated will cause some of the vapour to condense either as mist or droplets in the air or as dew or condensation on surfaces. One of the reasons for drying at elevated temperatures is that the moisture holding capacity of air is significantly increased at higher temperatures. As an example, the moisture holding capacity of air increases almost 20 fold when the air temperature is increased from 20° to 70 C (68° to 158 F).

3.3.2 DRY- AND WET-BULB TEMPERATURE

In kiln drying, RH is often determined through measurements of dry-bulb and wet-bulb temperature. Dry-bulb (DB) temperature is simply the temperature measured by a dry, exposed temperature sensor. Temperature sensors used in kilns are usually electronic in the form of a resistance temperature detector (RTD), thermistor, or thermocouple or may be a gas-filled bulb.

Wet-bulb (WB) temperature is the temperature measured when a temperature sensor, such as the type listed

above, is exposed to a moving air stream and the surface of that sensor is kept wet. This is usually accomplished by draping a wet cloth over the sensor with the lower end of the cloth immersed in water that is then wicked up to keep the surface of the sensor wet. Evaporation from that surface creates a cooling effect that causes a temperature somewhat lower than the DB temperature to be registered on the control system. If the air passing over the wick is saturated, then clearly there can be no evaporation from the wick and the DB and WB temperatures will be the same. This means the RH is 100 percent. When the air is less than saturated, that is, when it has a vapour pressure less than the saturated vapour pressure at the DB temperature, evaporation will occur from the wick. The WB temperature will then be lower than the DB temperature and the RH of the air will be less than 100 percent. Tables and charts are available which show the RH for any given combination of DB and WB temperatures as well as equilibrium moisture content. Table 3-4 shows some examples, with a wider range of conditions covered in Appendix II.

In wood drying, the term "wet-bulb depression" is often used as a means of describing the severity of drying. The wet-bulb depression is simply the difference between the dry-bulb and wet-bulb temperatures. For example, for a dry-bulb temperature of 120 F and a wet-bulb temperature of 110 F the wet-bulb depression (WBD) will be 10 F. Regardless of the dry-bulb temperature, an increase in the WBD will result in a lower RH and therefore a more severe drying environment. Likewise, a low WBD equates to a high RH and less aggressive drying conditions. Therefore, one way to compare drying schedules is by comparing the wet-bulb depression at different stages in the drying process.

3.3.3 EQUILIBRIUM MOISTURE CONTENT

If green wood is placed in an environment where the temperature and RH are kept constant, it will dry to a particular MC and remain at that level until the atmospheric conditions change. Similarly, dry wood will pick up moisture and rise to a particular MC in given conditions of temperature and RH. The MC at which wood neither gains nor loses moisture when subjected to given conditions of temperature and RH is called the equilibrium moisture content (EMC). A change in either temperature or humidity will cause a change of the EMC.

Tables and charts have also been prepared which show the relationships between dry-bulb and wet-bulb temperatures, RH and EMC. The following is an example of the inter-relationships between these:

Table 3-4

Relative humidity (RH) and equilibrium moisture content (EMC) as a function of dry-bulb (DB) temperature and wet-bulb (WB) temperature.

DB (°F)	WB (°F)	RH (%)	EMC (%)
90	80	65	11.5
90	70	36	6.8
90	60	13	3.0
130	120	73	12.0
130	110	52	8.2
130	100	35	5.9
170	160	78	11.7
170	150	60	8.2
170	140	45	6.2

A complete table covering a wide range of temperatures is presented in Appendix II.

EMC is a useful term in wood drying as it facilitates relating the drying conditions to the MC of the wood. As already stated, if the EMC is different than the MC of the wood, the wood will either gain or lose moisture until it reaches equilibrium. In addition, the greater the difference between the EMC of the air and the MC of the wood, the faster that rate of change will be. Therefore, in order to speed up drying, lower the EMC to widen the gap between the EMC and the wood MC. To raise or lower the kiln temperature without drastically affecting drying rate adjust the RH (or WB temperature) to assure the kiln is still running with the same EMC. Usually, drying schedules are constructed so that the EMC is continually being lowered throughout the period of drying. By remaining at the same EMC too long, the drying rate will slow down.

Another way in which EMC is useful is to consider what is going on with specific material within the load. Drying schedules with very low EMCs at the end of the schedule will result in more over-dried material. Faster drying material will tend to approach an MC close to the EMC faster than the rest of the material. If the EMC in a kiln is set at, for example, 12 percent, no material will drop below 12 percent. On the other hand, if the EMC is 2.5 percent, there is a much greater capacity to severely over dry some of the material. Another portion of the wood that is significantly affected by EMC conditions is the

surface of boards. Wood at the surface responds quite quickly to changes in EMC. The difference between core and surface MC in wood (the moisture gradient) is often the cause of certain drying defects. Given that the surface MC quickly approaches the EMC, one way of managing the severity of the moisture gradient is to pay close attention to the EMC condition in the kiln. These points are discussed in more detail in Chapter 15 (Drying Schedules).

3.4 FIBRE SATURATION POINT

Wood cells can be thought of as long tubes where both the walls and the hollow cavities can hold water.

The water that is contained in the cells of wood is in two forms; free water in the cell cavities and bound water located within the cell walls. The free water can be likened to water in a cup or bucket. There is no attachment of the liquid to the material the cup is made of and, likewise, for practical purposes it can be said there is no attachment of the free water to the substance comprising the cell walls. The difference is that we cannot "pour" the free water out of wood due to the minute and limited pathways available through which the liquid water must move.

Bound water is said to be intimately absorbed by the cell walls. The difference in this property between free and bound water greatly affects the drying process, both in the rate of drying and in the effects on wood properties due to drying.

As a piece of wood dries, the cavity of each cell empties first and only when the cavity has lost all of its water does the cell wall begin to dry. The condition of wood where the cell cavities no longer contain water, but the cell walls are still fully saturated, is an important stage in drying called the fibre saturation point (FSP). The FSP in most wood species occurs at a MC of between 25 and 30 percent. Virtually all kiln-dried softwoods are dried to a final MC target of 19% or less. Therefore, the process of drying involves removing all of the free water and, depending on the end use of the wood, a certain portion of the bound water as well.

As mentioned above, the FSP is not a precisely defined point in terms of MC. It will vary in relation to a number of factors including species, specific gravity, ambient (wood) temperature and other factors. When considering the effects of shrinkage it is often assumed that the FSP is 30 percent and calculations are based on that value as shown in the following sections.

In reality, when drying a piece of wood there is no point where the entire piece can be said to be at the fibre saturation point. This is because wood is dried from the outer surfaces and inevitably a moisture gradient is created. This means that the surface may reach the FSP long before the core. In fact, if a minute surface layer is considered, wood starts to shrink soon after it is placed in the kiln and long before the "average" MC has reached the FSP.

3.5 SHRINKAGE

Shrinkage is a normal, practically unavoidable process which occurs in drying any wood to a final MC below the FSP (25 to 30% MC). Shrinkage is one of the most undesirable characteristics of wood, but in itself shrinkage is not a form of degrade or damage. Shrinkage can, however, lead to drying damage such as splits and warp. A good understanding of the process of shrinkage and the factors which cause it and influence it will allow a kiln operator to take steps to minimize losses.

3.5.1 RELATIONSHIP BETWEEN SHRINKAGE AND MOISTURE

Shrinkage of wood cell walls is a gradual process. As more and more bound water leaves spaces between fibrils, so do more fibrils move closer and closer together. The onset of shrinkage in any one cell is when the first bound water is removed; shrinkage ceases when all of the bound water has been removed and that cell is at zero MC.

Between FSP and zero percent MC, the shrinkage is proportional to the change in MC. For example, assuming that the FSP is 30 percent MC, then in drying from 30 percent to 20 percent, one-third $(30 - 20) \div 30$, of the possible shrinkage will take place. In drying from 30 percent to 10 percent, two-thirds of the possible shrinkage will take place. Put another way, a wood cell wall will shrink by 1/30th of its possible shrinkage for each 1 percent drop in MC between 30 and 0 percent. This linear relationship between shrinkage and MC is shown in Figure 3-2 for black spruce.

When a piece of wood dries, the outer cells dry first, reach their FSP and begin to shrink before those below the surface. It is, therefore, possible for shrinkage to begin in a piece of wood while the average MC of the whole piece is above the FSP. In drying to any MC below the FSP, the wood will continue to shrink until all of the cells in the piece have reached the final MC.

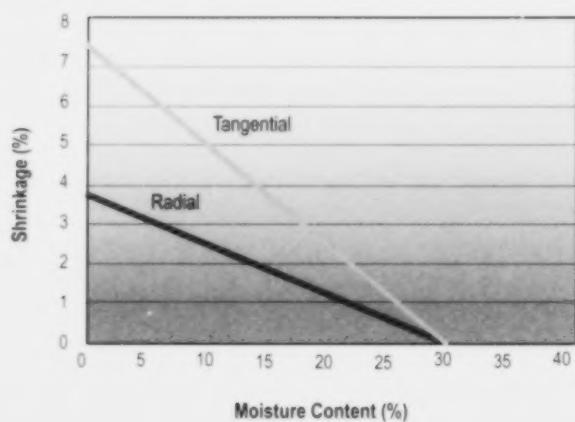


Figure 3-2

Radial and tangential shrinkage of black spruce as related to moisture content.

3.5.2 RELATIONSHIP BETWEEN SHRINKAGE AND THE SHAPE OF THE WOOD

Wood cell walls shrink in thickness, but very little in length; therefore, a piece of sawn wood will shrink in the across-the-grain directions, but an insignificant amount in the along-the-grain direction. Shrinkage in width and thickness is referred to as transverse shrinkage, transverse meaning in the across-the-grain directions. There are two principal transverse directions that can be observed on the end of a board or log, namely the radial (across the annual rings) and tangential (parallel to the annual rings) directions. The wide surface of a flat-sawn board is sawn in the tangential direction, i.e., at a tangent to the growth rings, so that the growth rings run parallel to the wide face. The wide surface of an edge-sawn board is sawn in the radial direction, i.e., along a radius between the pith and the bark, so that the growth rings run parallel to the narrow edge.

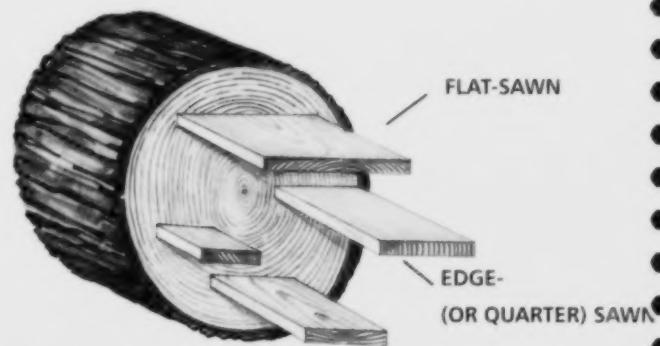


Figure 3-3

Log end showing various grain patterns in sawn lumber.

Shrinkage across the grain does not occur to the same extent in all directions. Due to the restraining effect of some anatomical features acting in the radial direction, shrinkage in the radial direction is about half that of the shrinkage in the tangential direction. It follows from this that if two identical size boards are sawn from a log, the one flat-sawn and the other edge-sawn, and dried to the same MC, then;

- (a) the flat-sawn board will shrink twice as much in width as the edge-sawn board;
- (b) the edge-sawn board will shrink twice as much in thickness as the flat-sawn board.

Such differences in shrinkage are the most common causes of warp in sawn lumber. A flat-sawn board, which is allowed to dry without any means of holding it flat, will tend to cup away from the heartwood side. This is because the growth rings are more parallel on the sapwood side; therefore more tangential shrinkage takes place on this side of the board than on the heartwood side. A square piece of wood with sides truly flat-sawn and edge-sawn will shrink to become rectangular in shape. However, if the growth rings run diagonally across a pair of opposite corners, then the difference in shrinkage will cause the square section to become diamond shaped. Examples of deformations caused by differential shrinkage are shown in Figure 17-8.

The size of the cross section of sawn lumber influences the amount of shrinkage that develops. In general, pieces of larger cross section shrink proportionately less than those of smaller cross section. This is due to the outer zone of large-section lumber drying while being prevented from shrinking by the large central core of wetter unshrunken wood. In thin cross sections, the surface and the inner zone of the wood tend to dry at similar rates and, therefore, they shrink together. Since neither zone restricts the other from shrinking, the total shrinkage in thin cross sections is proportionately more than in thick cross sections.

3.5.3 MEASUREMENT AND CALCULATION OF SHRINKAGE

In most situations an operator will be concerned with determining shrinkage to a specific final MC rather than the process for determining total shrinkage as described earlier. How much wood will be left if the wood is dried to, for example 12% MC? The standard method of expressing shrinkage in wood is as a percentage of its green size in the tangential and radial directions when dried to a given MC.

Total shrinkage values have been developed for most commercially important species and those for SPF are listed in Table 3-5. Calculated values to specific final MCs between FSP and oven-dry are listed in Appendix III.

Using white spruce as an example, Appendix V shows that this species can be expected to shrink 1.6% and 3.5% in drying from green to a final MC of 15%. It may be necessary to know, in absolute terms, how much this lumber will shrink in drying to that MC. The shrinkage formula is:

$$\text{Actual Shrinkage} = \frac{\text{Green Dimension} \times \text{Percent Shrinkage}}{100}$$

As an example of this, assume a truly edge- (quarter) sawn board measuring exactly 6 inches by 2 inches.

$$\text{Tangential (thickness) shrinkage} = 2 \times 3.5/100 = 0.07 \text{ inches}$$

$$\text{Radial (width) shrinkage} = 6 \times 1.6/100 = 0.096 \text{ inches}$$

Therefore, the final dimension values are:

$$\begin{aligned} \text{Tangential (thickness)} &= 2 - 0.070 = 1.930 \text{ inches} \\ \text{Radial (width)} &= 6 - 0.096 = 5.904 \text{ inches} \end{aligned}$$

If this had been a flat-sawn board the tangential shrinkage value would apply to the width and the radial value to the thickness. In this case, the final thickness and width of the board described above would have been 1.968 inches and 5.790 inches, respectively.

It is important to use the correct shrinkage values, so that tangential shrinkages apply to the width of flat-sawn boards and the thickness of edge-sawn boards; whereas radial shrinkages apply to the thickness of flat-sawn boards and the width of edge-sawn boards.

When considering a load of lumber it is usually not possible to specifically state the grain direction for either the thickness or width. To calculate the shrinkage allowance for a sawmill target size consider a worst-case scenario. In this event assume and calculate based on tangential shrinkage values in both directions. However, a quick inspection of the lumber may reveal that most pieces are flat-sawn and this would justify applying the radial shrinkage value to the thickness and the tangential value to the width. Another consideration is the final MC value to apply. In the above example a final MC of 12% was assumed, however, even the best drying operation cannot achieve total uniformity in final MC. Therefore,

when trying to arrive at a worst-case value for shrinkage it is necessary to consider the lowest MC the material is dried to. Considering the above example again, assume that the moisture check has shown that some material in the load is actually dried as low as 9% MC. In this case, there is no pre-calculated value listed in Appendix V and it is necessary to make an adjustment for final MC. The following paragraphs describe the procedure for this.

As mentioned earlier an alternative method of expressing shrinkage is as the maximum or total shrinkage. This simply refers to the shrinkage from at, or above, the FSP down to zero percent MC. Values for total shrinkage are listed in Table 3-5.

For example, assume that a green flat-sawn, white spruce board 10 inches wide is to be dried to 10% MC. The FSP is 30% MC and the total tangential shrinkage for this species in the tangential direction is 6.9%. How much will the board shrink in width when it dries to 10% MC?

The problem cannot be solved in one step. First, it is necessary to calculate by what percentage it will shrink. Remember that shrinkage is proportional to the drop in MC from fibre saturation point to zero percent MC.

$$\text{Shrinkage (\%)} = \left[\frac{(\text{FSP} - \text{Final MC})}{\text{FSP}} \right] \times \text{Total Shrinkage}$$

$$\text{Shrinkage (\%)} = \left[\frac{(30 - 10)}{30} \right] \times 6.9$$

$$\text{Shrinkage (\%)} = 4.6\%$$

That is, when the board dries to 10% MC, it will shrink in width by 4.6%. The second step is to calculate the actual amount of shrinkage. This is done by using the shrinkage formula listed earlier:

$$\text{Actual Shrinkage} = \frac{\text{Green Dimension} \times \text{Percent Shrinkage}}{100}$$

$$\text{Actual Shrinkage} = \frac{10 \times 4.6}{100} = 0.46 \text{ inches}$$

Subtracting 0.46 inches from 10 inches, the final width of the board will therefore be 9.54 inches. This procedure can be applied to any situation where the species and final MC are known.

A simplified procedure to calculate shrinkage to specific MC levels is presented in Appendix V.

Species	Radial Shrinkage (%)	Tangential Shrinkage (%)
Black spruce	3.8	7.5
Red spruce	4.0	7.9
Jack pine	4.0	5.9
Balsam fir	2.7	7.5
White spruce	3.2	6.9
Engelmann spruce	4.2	8.2
Lodgepole pine	4.7	6.8
Alpine fir	2.6	7.4

Table 3-5

Total shrinkage values for SPF species in the radial and tangential directions.

3.5.4 EFFECT OF WOOD TYPE ON SHRINKAGE

Normally wood shrinks only transversely, but there are some abnormal forms of wood which shrink significantly along the grain. Reaction wood is the most common example, this being the wood that forms in branches and leaning stems. In softwoods, it forms on the underside of leaning stems and is called compression wood.

Compression wood is usually recognizable by its appearance. In a log it does not fill the complete circuit of a growth ring and, therefore, in cross section it is found in a half-moon pattern. The growth rings in compression wood are unusually large and appear to have a high percentage of latewood. It usually has a deep red colour and in boards the wood has a dull lifeless appearance.

This type of wood has an unusually large amount of longitudinal shrinkage. Since compression wood normally occurs in streaks or pockets in sawn lumber, there is an interaction between normal wood resisting longitudinal shrinkage and the compression wood trying to shrink. This results in severe local distortions when the boards dry.

Other types of wood have been found to have measurable amounts of longitudinal shrinkage, which are important enough to cause problems during drying. Wood with spiral or sloping grain sometimes occurs where the wood cells do not lie parallel to the length of the board. As they shrink in drying, they collectively cause the length of the board to shrink and distortion in the form of twist can result. Juvenile wood from near the pith (core) of a tree will often exhibit greater than normal amounts of longitudinal shrinkage. A board that has juvenile or compression wood along one edge and normal wood

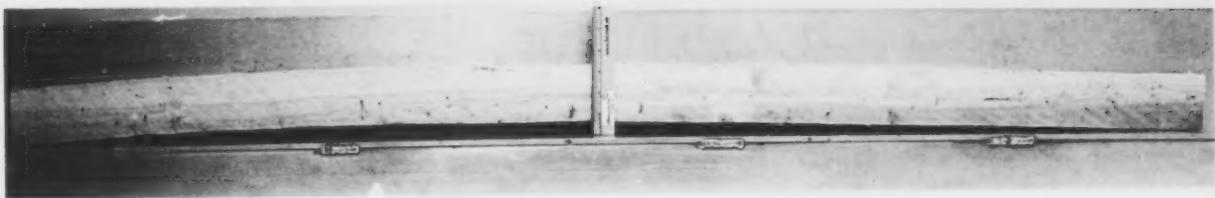


Figure 3-4

Edgewise distortion (crook) in this board has been caused by compression wood (the darker-coloured fibre) along the bottom edge of this board shrinking more than the normal wood on the opposite edge.

fibre along the opposite edge will develop a differential shrinkage situation as the wood dries below the FSP. In this case, the board is likely to develop a sideways deflection (crook) as shown in Figure 3-4.

3.6 MOISTURE REGAIN AND SWELLING

To this point, the only change in wood size due to MC changes that has been described is shrinkage due to loss of MC below FSP. However, if dry wood is placed in a humid atmosphere, then the wood cell walls are capable of taking up moisture and swelling. This is caused by the reverse of the mechanism described earlier under shrinkage. Now, moisture in the form of bound water enters the spaces between the fibrils in cell walls, the walls swell and therefore the across-the-grain dimensions of the wood increase.

While the principal concern in lumber drying is reaching a low enough MC, problems can arise if lumber is too dry. For example, furniture constructed with wood dried to a low MC can be seriously damaged by wood swelling and the glued joints breaking if it is placed in an excessively humid atmosphere.

Moisture regain can also be an issue if the wood MC is elevated beyond what the customer has specified. As described above, an EMC level higher than the MC of the wood will cause the wood to regain moisture. This type of moisture change involves only changes in relative humidity of the air and the amount of bound water in the wood. Therefore, the only concern is when the EMC exceeds the target MC. If, for example, lumber is dried to 19% and less, the only way to regain moisture in the manner described above would be if the EMC was in excess of 19%. At 70°F it would take a relative humidity of 88% or higher (see Appendix II), sustained over a considerable amount of time to elevate the MC of such material. Therefore, the material that is at most risk of moisture regain from the atmosphere is that dried to

much lower final MCs. In practical terms it is only material dried to 12% or less that will require some form of protection from conditions of high relative humidity. In most instances, if the wood MC has been elevated beyond 19% after drying, it is because of exposure to some form of liquid water such as rain, melting snow or puddles of water on the ground. It is usually protection from these sources of moisture that must be addressed when storing or shipping softwood dimension lumber.

3.7 COLLAPSE

There exists a totally different form of shrinkage in some wood species, which is commonly referred to as abnormal shrinkage or collapse. It is very important to recognize the differences between normal shrinkage and collapse.

The commonly accepted theory for explaining the phenomenon of collapse is as follows. In very wet wood, the cavities of a number of cells may be entirely filled with liquid free water, with no room being left for air. As these cells dry, air should enter the cell cavities to replace the free water moving out. The passage of air through wet wood is very slow, however, and the free water can pass out of the saturated cells faster than the air can enter, especially when heat and low humidity conditions are being applied. When this happens the cell walls are drawn together by capillary tension forces and they will buckle and fold to the extent that the cell cavity is completely closed. Note that it is not the external air pressure on the outside of the wood which is responsible for this collapse, but rather the cohesive force of the water pulling the wet cell walls together. The collapse of groups of many cells produces sunken areas in the surface of lumber giving a washboard effect, and in thick lumber internal checks may also develop.



Figure 3-5

Collapse in this board has resulted in a sunken or depressed area on the surface.

The main difference between collapse and normal shrinkage is that collapse occurs only in cells which are losing free water from the cell cavities, whereas normal shrinkage occurs only in cells whose cavities are empty of free water and whose walls are losing bound water. Therefore, collapse can occur only in cells well above FSP and normal shrinkage can occur only in cells below FSP.

These are some characteristics of collapse:

- It is very rarely found in sapwood because sapwood is generally more permeable than heartwood and air can enter cell cavities as the free water is moving out.
- It occurs more frequently in species that have a very high initial MC combined with poor permeability characteristics. Examples of species from the SPF grouping prone to collapse are balsam and subalpine fir, and red or white spruce (especially plantation grown stock).
- It occurs more in earlywood than in latewood because earlywood cells have thinner walls and, therefore, provide less resistance to the forces pulling the walls together.
- It creates a washboard effect on the surface, the raised areas being the latewood bands which have collapsed less than the earlywood bands.

Cell walls become soft and plastic when wood at a high MC is heated; collapse is therefore more liable to occur when excessively high temperatures are used in kiln-drying. If a particular species is known to be prone to collapse, then one solution is to air-dry the lumber before kiln-drying.

WETWOOD DRYING IMPLICATIONS

4.1 DEFINING WETWOOD

Wetwood is a condition present in certain tree species that has a very pronounced effect on the wood's drying properties. In general wetwood has a higher MC and slower drying rate than normal wood. A link has been identified between the presence of anaerobic bacteria and the presence of what is recognized as wetwood. From the SPF species grouping both balsam fir and sub-alpine fir are heavily affected by the presence of wetwood. The problem caused by wetwood is not so much that it dries slowly but that it is difficult to identify (and isolate) and therefore it is dried with other, much faster drying, material. Any time material with varying drying properties is mixed, the kiln operator's task becomes a lot more challenging.

The bacteria associated with wetwood may have entered the tree through the roots (from the soil) or through wounds, i.e., broken branches along the stem. In either case, it is clear that the cause of the problem originates with the standing, live tree. The extent that wetwood is present in a particular board or log varies considerably; this is likely the result of various stages of infestation by the bacteria. Given that the bacteria spread from single or multiple points of entry, it takes time for the entire tree or log to become affected. In the process of producing lumber from logs, we inevitably cut through infected and non-infected areas. This results in some lumber that is heavily affected by wetwood and other pieces that are lightly or not affected at all. This also explains why even within a single piece of lumber, one portion may contain wetwood while the rest of the board dries quite normally.

One of the side effects associated with wetwood is the presence or apparent development of shake during kiln drying. It is believed that the bacteria described above have an effect on intercellular material (the middle lamella) in the area separating one annual ring from another. This causes a line of weakness along the annual rings. Sometimes the shake can be observed in green

lumber, in which case it can be used as an indicator of areas prone to wetwood. Most often it cannot be seen until after drying when the wood has shrunk and been exposed to some drying stresses which result in these lines of weakness opening up and the shake becoming more apparent.

4.2 DETECTING WETWOOD

There are a number of wood characteristics that are often associated with wetwood but, as yet, there is no definitive way of identifying wetwood in green lumber. Wetwood is generally recognized by the moisture patterns present in either green or dry lumber. In green lumber it is typically detected as darker areas on the board surface which appear wetter than surrounding wood. Figure 4-1 shows a sample of green subalpine fir with the presence of darker streaks in the wetwood zone. These darker zones often appear in a mottled pattern that does not necessarily follow the grain pattern in the material.



Figure 4-1

Sample of green subalpine fir with the presence of darker streaks in the wetwood zone.

Over the course of the drying period, lumber inevitably develops a moisture gradient. If no special treatments, such as conditioning, are conducted, the lumber will end up with a shell that is somewhat drier than the core. The severity of the moisture gradient is influenced by the severity of the drying schedule employed. These subjects

are discussed in more detail in Chapters 15 through 18. The presence of wetwood in a board interferes with the development of a normal moisture gradient. Figure 4-2 shows both a normal moisture gradient and a non-normal gradient that would be typical of a piece of kiln-dried lumber containing wetwood. In the normal sample, there is a regular (and predictable) increase in moisture in the progression from any surface toward the core. In the sample containing wetwood, there is no predictable pattern to the moisture gradient. Zones within the cross section that were heavily infected will have dried much more slowly while normal wood, even a few centimeters away, may have dried quite readily. Figure 4-2 shows a photo of a cross section of a board containing wetwood shortly after removal from the kiln.

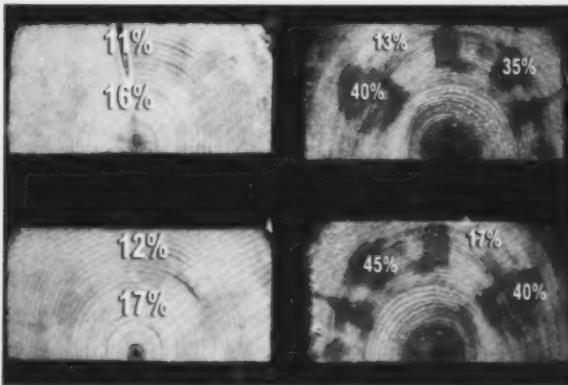


Figure 4-2

Photograph of board ends showing wet pocket and non-wet pocket pieces.

When a moisture meter is used to sample dry MC of lumber, wet pockets are detected by the random nature of high versus low readings. For example, five meter readings taken along the length of a board all indicate a very low final MC but the sixth reading gives an MC estimate of 35%. This would be typical of material containing wetwood.

Other species with wetwood often have characteristics that make it easier to identify affected material in the green condition. For example, oak with wetwood will tend to have a vinegar-like smell. Various tests have shown that wetwood areas will also have a lower pH (more acidic) than normal wood. As a result, kilns drying a lot of wetwood material will develop more corrosion problems due to the acidic nature of condensates formed on the walls. Many species, including subalpine and balsam fir will tend to develop a different colour in wetwood areas. The colour difference is quite subtle and is usually just a slightly greyer area.

To further complicate the matter, it is not always the wettest boards that have the bacterial infection. There is no direct link between initial MC and incidence of wet pockets after drying. Earlier tests at Forintek on white pine indicated that material from near the middle of the initial MC range was more likely to contain wetwood than material from the high end. In this case (and quite likely with other softwood species prone to wetwood) the highest MC material was sapwood. Sapwood is quite permeable and, although its initial MC is high, it dries quite readily and can normally be included with lower MC "normal" heartwood. Green MC testing on balsam fir from Eastern Canada gave a range from 41 to 207%. The lowest material is most likely all normal heartwood; the highest MC material (i.e., 160% and higher) is likely all fast-drying sapwood; while the mid-range MC material would be more likely to contain wetwood. Therefore, in-line, green MC detectors cannot be relied on fully to separate material with wetwood.

The following visual characteristics will help identify balsam fir that has a greater tendency to contain wetwood:

- Boards containing a greyish discoloration will tend to develop a higher incidence of wet pockets.
- Boards displaying a blotchy or mottled appearance of wetter and drier zones will tend to develop a higher incidence of wet pockets.
- Boards displaying any degree of shake in the green condition will tend to have a higher incidence of wet pockets after drying.
- Boards looking very wet but looking consistently wet across a wide surface area may be sapwood and will therefore dry quite readily. Signs of wane or noting the position of the board from within the cross section of the log may help confirm that the material is indeed sapwood. This material can be left in with faster drying material.
- Heavy boards which are obviously not sapwood, i.e., containing pith, should be considered as wetwood and kept with the slower drying material.

Some mills have trained staff to recognize these characteristics and implemented a pre-sort based on a visual inspection of the green lumber.

4.3 EFFECT ON DRYING PROPERTIES

It is well understood that material containing wetwood dries more slowly than normal material of the same species or other species from the SPF grouping. From

laboratory testing on balsam fir and subalpine fir it has been determined that, sapwood has the greatest permeability, heartwood the lowest, and wetwood somewhere between the two. Therefore, differences in permeability alone do not fully explain the differences in drying time encountered in practice. Whatever the mechanism, it is clear that the impact on the drying properties is most pronounced while there is still free water present in the wood. Once the wood is reduced below the FSP (25 to 30%), the movement of bound water is not affected by the factors listed above. Keep in mind that achieving an average MC below the FSP does not always mean that all free water is gone. A normal moisture gradient or wet pocket surrounded by dry wood may still explain the presence of free water. Therefore, when drying construction grade lumber to 19% or less, the presence of wetwood has an impact for most, if not all, of the drying cycle.

4.4 EFFECT ON DRYING RATE

A previous Forintek study showed that high MC balsam fir (average of 129%) required 161 hours to dry versus 124 hours for material starting at a lower initial MC (85%). Another study identified a range of drying times for material at different starting MCs and specific gravity levels. The results of that test are summarized in Table 4-1. Drying time increased with increases in both initial MC and specific gravity.

Table 4-1

Summary of drying time results from laboratory tests on Eastern balsam fir (Savard, 1995).

Description	Initial MC (%)	Specific Gravity	Time to Dry (hrs) ¹
Low Initial MC Low Specific Gravity	88.3	0.31	113
Low Initial MC High Specific Gravity	83.4	0.36	122
High Initial MC Low Specific Gravity	131.6	0.30	156
High Initial MC High Specific Gravity	122.2	0.36	167

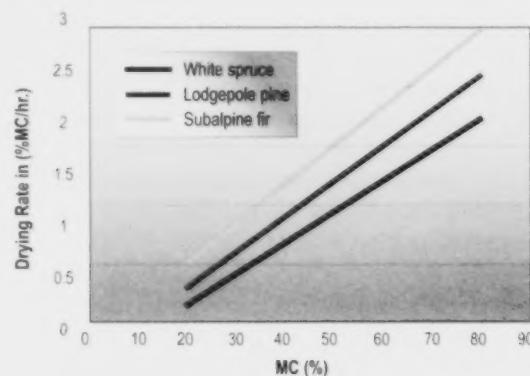
¹Drying time defined as time for 95% of material to reach 19% MC or less

Another Forintek study showed similar results for subalpine fir. In those tests, drying rate was measured in %MC/hour at different stages of the drying process.

Figure 4-3 shows a comparison of drying rates for the three main species in the SPF grouping from Western Canada. This graph shows the results for material sorted as having a high initial MC. It shows that subalpine fir dries more slowly than spruce or pine at all MC levels but that the discrepancy is greater at higher MCs. This again demonstrates that wetwood material not only has a higher MC but does indeed dry more slowly. Similar results were shown for material sorted as mid-MC but for material sorted with a low initial MC the drying rates for subalpine fir were similar to spruce.

Figure 4-3

Drying rates in western SPF



4.5 WAYS OF DEALING WITH WETWOOD PRONE SPECIES

The previous sections of this chapter have dealt with describing how and why wetwood material is different and how much of an impact it has on the drying properties. These explanations help the kiln and mill operators understand the need to apply different techniques when drying material with wetwood. This section will present some of the techniques that are available to help dry this difficult material.

Two variables that impact on the decision of how to deal with wetwood are the percentage of subalpine or balsam fir present and the quality of that portion of the lumber mix. Mills that are lucky to have a very small percentage of fir in their mix (i.e., less than 10%) can often get away with leaving it in the lumber mix and not having it significantly affect their drying operation. As discussed previously, a certain proportion of fir will be adequately dried using a normal spruce or pine schedule. Therefore, if the overall percentage of fir present is low, any "wets" remaining in the load can either be tolerated in the final product or easily removed and sold as an "off grade" product. The next consideration is the quality of the fir contained in the lumber mix. Based, to a large extent,

on the conditions of the growing region, balsam or subalpine fir in some regions of the country will exhibit less problems with wetwood. This again, is another basis by which a certain proportion of fir can be tolerated in the lumber mix without having to modify the drying operations. Some mills are able to manage the problem simply by limiting the amount of fir allowed into the sawmill. If sorted in the bush, excess fir can be re-directed to other operations or run separately as a "green" product.

4.5.1 DRYING WETWOOD WITH NORMAL MATERIAL

Drying material with different drying properties together is always a compromise situation. The operator must decide what aspect(s) of the drying operation can be compromised and to what extent. For example, dry slowly and negatively affect kiln productivity or dry more aggressively and accept more rejects from "wets" and extra warpage in over-dried material. The answer will be different in each situation as each mill not only has its own unique log mix but also unique demands as far as productivity objectives at the kilns and quality expectations for the lumber.

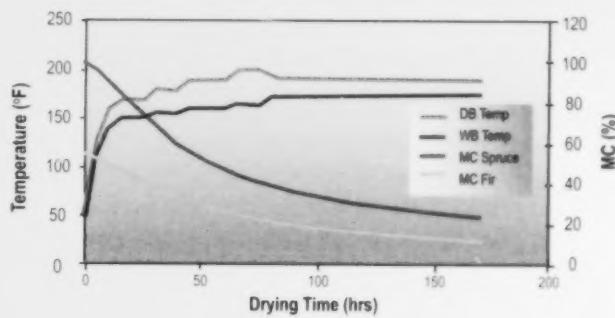
Slow and fast drying material can be dried together with good results (with regard to lumber quality). This is achieved by running with a relatively mild drying schedule and incorporating a long equalization treatment at the end of the cycle. This is the only way to avoid over-drying the faster drying material and to ensure the slower drying material reaches the intended final MC. Unfortunately, the required drying time is often so long that most mills cannot afford, either for productivity or economic reasons, to implement this measure. It should be kept in mind that when mixing any two groups of lumber with different drying characteristics in the same kiln, the drying cycle required to achieve a good quality final product will, in most cases, be longer than the drying cycle for the slowest drying material in the group if it were dried alone. This is a result of having to "back off" on the drying schedule and begin equalizing once the faster drying material has reached, or almost reached, the intended final MC. The concept is shown diagrammatically in Figure 4-4. It can be seen in this Figure that the drying rate of both fir and spruce decrease significantly once the equalization phase begins. Drying schedules for mixed species and the concept of equalizing are covered in more detail in Chapter 15.

4.5.2 DRYING BALSAM OR SUBALPINE FIR ALONE

Extracting and drying species containing wetwood on their own does achieve some advantage over drying them in mixture with other species. In the case of SPF, the main benefits are those realized by drying the other

Figure 4-4

Drying schedule with an extended equalization treatment added at the end.



species without balsam or subalpine fir present. Drying times for the majority of the spruce and pine species included in the SPF grouping are much better matched than when subalpine or balsam fir are included. Therefore, drying the remaining species together produces a much better result in terms of improved final MC uniformity and reduced drying degrade. The question then becomes what to do with the fir species (or other wetwood species) when they are dried alone.

Drying tests on a small-scale research kiln at Forintek demonstrated that the variability in drying time within the balsam fir population is quite significant. Those tests showed that some boards were dry in as little as 27 hours while other pieces took up to 151 hours. Putting material with such differing drying characteristics into the kiln together ends up with the same compromise situation described above for the mixed species. As with the mixed species, one of the potential solutions is to employ the use of lengthy drying schedules incorporating an equalization treatment. The same compromises exist as above.

Air drying is an option that becomes more viable once the particular fir species that you are dealing with has been separated. Air drying achieves the same objective as a long-slow drying cycle with equalization. Outdoor EMC (equilibrium moisture content) conditions are relatively mild when compared to most kiln schedules. In most areas of the country it is impossible to dry the material any lower than 12 to 15%, and even this is only obtained after one or two full drying seasons. The objective in air drying balsam or subalpine fir is to reduce or eliminate the free water present. As mentioned previously, the wetwood effect is only significant when the wood is above the FSP. By air drying the lumber to a MC near the FSP, it can then be dried on a more aggressive schedule once it reaches the kiln with less likelihood of developing wet pockets or

excessive drying degrade. A Forintek study on Eastern SPF showed that after 6 to 8 weeks air drying under spring/summer conditions, balsam fir could be mixed with green spruce and pine for a final kiln drying cycle more typical of the drying time for spruce and pine. More detail on air drying is presented in Chapter 13.

Another manner in which air drying is being employed is as a full drying treatment rather than an initial treatment for the material. If the percentage of balsam fir is relatively low, it may make sense to let the material air dry until it has reached the required final MC. Again, the procedures on how to do this are well described in Chapter 13 along with some data on drying rates. If an air drying yard is being set up, it is important to take measures to ensure as rapid and uniform a drying rate as possible. As mentioned above, it is quite possible, in most areas of the country to obtain a final MC of 19% or less. According to the NLGA grading rules this material can be stamped as "S-Dry". Recently, however, the need to heat treat material that may be exported has caused mills that were, or are considering, air drying to re-evaluate how they do things. With the need to reach 56 C in the core of the material it is necessary to put the lumber into a kiln (or heat-treatment chamber) at some point in time. If air drying is used as a pre-treatment to kiln drying then this is usually not an issue (see section on heat treatment). Another way of addressing this concern is to place the material into the kiln for a rapid heat treatment prior to placing it in the yard for air drying. Either method is acceptable from a phytosanitary standpoint.

Some mills have employed the use of low-temperature dryers to dry subalpine or balsam fir. Again this achieves the same objective as an equalization treatment. An advantage in operating such a system is that it is easier to maintain higher EMC levels at the lower operating temperatures in these kilns. Drying times will be considerably longer than a conventional or high-temperature kiln but shorter and more predictable than air drying. If you intend to dry wetwood material alone at low temperatures, the installation of a purpose-built low temperature dryer should be considered over using a conventional kiln and running it at low temperature. Capital and operating costs for a low-temperature kiln will be less than those for an equivalent capacity conventional kiln.

Aggressive drying routines do not work well for balsam or subalpine fir. Whether it is being dried at low or high temperature, a large depression at the start of the schedule will cause cell collapse. An initial depression of more than 15 to 20 F (8 to 11 C) should be avoided. More details on drying schedules are presented in Chapter 15.

One reason why low temperature drying works better on these fir species, is that it is easier to achieve and maintain a low depression at lower dry-bulb temperatures.

4.5.3 SEPARATING WETWOOD FROM NORMAL WOOD

Some of the characteristics described earlier in the sections "Defining Wetwood" and "Detecting Wetwood" can be used to make a separation within balsam or subalpine fir. The objective is to remove the difficult-to-dry portion from the easier-to-dry portion. As mentioned earlier there is a portion of the wood that will dry on schedules more typical of spruce and pine. The trick is to identify those pieces and remove them. Some mills do a visual sort based on the characteristics described in the earlier sections of this chapter. Other mills employ some sort of technology to try to automate the process of differentiating the material. Green MC detectors have been employed in the past. A hurdle with these systems is to find one that is not affected by other wood properties and, in particular, variations in specific gravity. At this time there are no technologies on the market that can be described as true, green MC meters. Other technologies based on RF measurements or measuring board weight have been developed and are being employed. In each of these cases, the measurement that is being made is in part influenced by the amount of wood present (i.e., specific gravity) and the amount of water present. Board-to-board differences in both of these variables are significant, from a drying standpoint, when one species is being processed (whether that species has wetwood or not). When multiple species are being processed differences in specific gravity from one species to the other will complicate the process of identifying and sorting difficult-to-dry material from the easier-to-dry material.

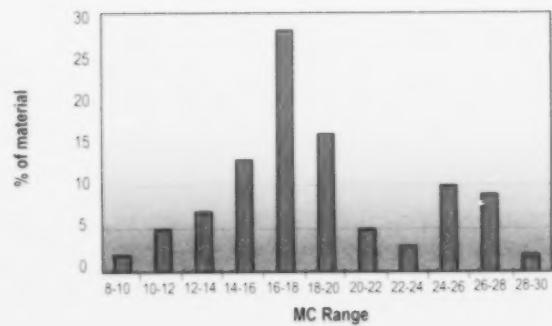
Once a separation has been made between the difficult and easier-to-dry portions of a wetwood species, it is possible to develop drying routines that meet the demands of each group. Often, the easier-to-dry portion of balsam or subalpine fir can be mixed with spruce and pine and dried on a normal schedule for those species. The difficult-to-dry portion can then either be air dried, partially air dried, or dried in a kiln using a long, mild drying schedule. By minimizing the portion of the material that absolutely needs to be dried on a long, slow schedule several advantages are realized. The easier-to-dry portion can be dried on a more aggressive schedule with less risk of downgrade and a positive impact on kiln productivity. Time saved on drying the easier-to-dry material can then help justify devoting a longer kiln cycle to the difficult-to-dry material.

4.5.4 RE-DRYING MATERIAL WITH WET POCKETS

All of the measures discussed up to this point have involved solutions to the problem of wetwood that can be implemented before or during the drying of the lumber. An alternative to these options is to address the problem after the dry kiln. Whether subalpine or balsam fir is dried on its own or with other species a wide range of final MC will result. Figure 4-5 shows a typical moisture distribution toward the end of the drying cycle for a SPF mix containing one of the wetwood species. If a charge like this is exposed to harsh drying conditions, the material at the low end of the MC range will become well over-dried and develop extra degrade due to warp (see section on effect of final MC on drying degrade in Chapter 17). An alternative is to prematurely remove the material from the kiln, scan it with an in-line moisture meter and separate the material that needs re-drying. The net effect is usually a reduction in average drying time as well as an improvement in grade recovery. The down side is the extra handling involved and the need to install a moisture measuring system and equipment to remove "wets" before the planer.

Figure 4-5

Typical distribution of final MC in mixture of spruce and fir (subalpine or balsam).



"Wets" are boards that are removed from the semi-dry lumber mix but they are not wet in the sense that they are still green. They are likely a mix of slow-drying normal wood (the smaller proportion) together with boards containing wetwood. These wetwood pieces will have varying amounts of wetwood present and therefore, even a charge of material selected for re-drying will exhibit a wide range of moisture conditions and represent material with a wide range of drying characteristics. Some pieces may need only a short re-drying cycle while others will still require a considerable amount of time to reach the desired MC. Therefore, the best way to handle such material in a conventional kiln is to run it on a gentle

cycle and essentially equalize the load. Suggestions on schedules for re-drying are presented in Chapter 15.

The re-drying step can be achieved in a conventional kiln, as described above, or with some other type of drying system. Considerable attention has been given to linking radio-frequency vacuum (RFV) drying with a conventional kiln. The rationale for this is as follows. The material can be dried on a shortened cycle in the conventional kiln and "wets" removed for re-drying. The material selected for re-drying can then be accumulated and prepared for re-drying. Lumber does not need to be piled on stickers for RFV drying and this would therefore facilitate the handling and re-piling of "wets". A RFV kiln can achieve relatively fast drying times (see description of drying systems in Chapter 7) and therefore a small-volume chamber can be used to handle the re-drying needs of a much larger conventional kiln(s). This concept has been installed on a commercial scale for Western Hem-Fir (another species mix with a wetwood problem) and has been proposed for SPF applications. Tests conducted by Forintek and Hydro Quebec have demonstrated the technical feasibility. Tests on re-drying of 2-inch black spruce demonstrated a drying rate almost 4 times faster than conventional drying. The RFV kiln was able to achieve an average moisture loss of 2.2% MC per hour versus 0.6% MC per hour in a conventional kiln. At this time, however, this option is not economically viable as the equipment and operating costs are higher than alternative re-drying systems.

As with any equipment or process decision, the ultimate criteria are the impact on production cost and/or product value. Re-drying presents an opportunity to have a positive impact on both of these criteria and should not be overlooked as an option. This is especially true when designing and setting up a new drying operation and the process can be designed to accommodate the material flow needs of a re-drying system. Even if re-drying is not considered at the outset, designing a mill to maximize the opportunities to sort and re-handle material at different points in the process will keep options open for the future. This may be as simple as leaving space to accommodate future changes.

DETERMINATION OF WOOD MOISTURE CONTENT

5.1 OVERVIEW

Moisture content (MC) is the most important material property to be evaluated in a lumber drying operation. From green to dry, and all the stages in between, accurate data on MC is critical if correct decisions or judgments are to be made. Unfortunately, there is no one method of measuring MC that is both accurate enough and practical for application in all situations where wood MC information is required. This chapter will highlight the various methods for measuring MC. The method used in any specific application will depend on the level of accuracy required and the time available to produce results.

5.2 OVEN DRYING METHOD

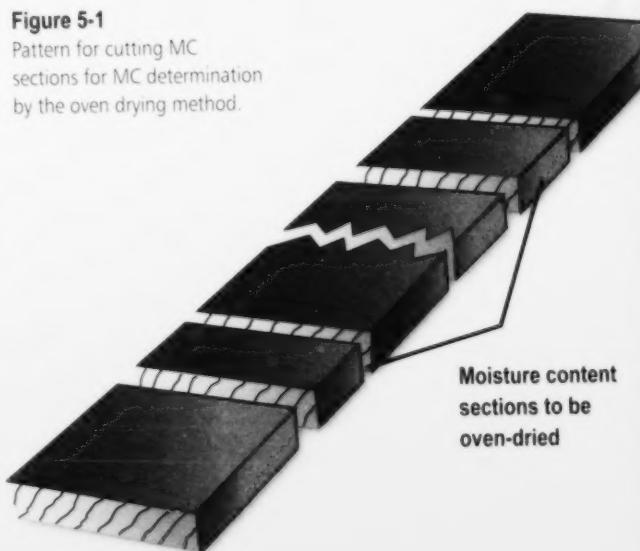
The standard way of determining wood MC is known as the oven drying method. This direct method which is applicable to all species including SPF, provides a very accurate measure of wood MC over the entire moisture range from fresh green wood to kiln-dried. This method also serves as a standard against which a number of indirect moisture measuring systems can be calibrated and compared.

As an example assume that the average MC of a board is to be determined. The following are the step-by-step procedures which are recognized as providing the most accurate result.

1. Cut and discard about 2 feet (0.6 m) from each end of the board. This is done to eliminate the possibility that drying has already occurred from the ends of the board.
2. Cut a section about 1-inch (25 mm) long along the grain from each of the freshly cut ends. These sections, which will be used for MC determination, should be free of knots, rot, pitch pockets or any other imperfections.
3. Remove all loose splinters and sawdust from the sections.

Figure 5-1

Pattern for cutting MC sections for MC determination by the oven drying method.



4. Weigh the sections immediately and record these measurements as original or green weights. If there is a delay before weighing, the sections should be tightly wrapped in a plastic bag. An electronic balance capable of indicating weight to a precision of 0.1 grams is the preferred way of measuring sample weight.
5. Place the sections in a ventilated oven at 215° to 220° F (102° to 104° C) and allow them to dry until they have reached a constant weight. Normally this will require 18 to 24 hours and at that point the wood is assumed to be at 0% MC.
6. Immediately reweigh the sections and record the measurements as oven-dry weight.
7. Apply the method shown earlier (Chapter 3) to calculate the MC of each section, example:

Section 1	Original Weight	=	80 grams
	Oven-dry Weight	=	47 grams
Moisture Content = $\left[\frac{(80-47)}{47} \right] \times 100 = 70\%$			

Section 2	Original Weight	=	101 grams
	Oven-dry Weight	=	54 grams
Moisture Content = $\left[\frac{(101-54)}{54} \right] \times 100 = 87\%$			

Since the moisture sections were taken from opposite ends of the board, the average of the two MCs, (78.5%), can be used as an estimate of the average MC of the board.

One of the disadvantages of an oven test is the time required to get the results. One way to shorten the time is to use a microwave oven to dry the samples. Since microwave ovens vary considerably in power ratings and features it is impossible to give a specific routine to follow. The danger with a microwave oven is the potential to burn the sample, which normally starts in the interior of the sample and is well progressed by the time it is detected. The way to avoid this is to use a lower power setting and to cycle the sample in and out of the microwave to allow some cooling. It may be possible to reduce the overall time to get the results but the manpower required to conduct this test will often be greater than conducting a standard oven test.

Since the oven test is time consuming and also destructive, in that a sample must be cut from each board that is to be evaluated, there is a need for some alternative ways to assess MC in kiln-dried wood.

5.3 ELECTRICAL METHODS

For industrial use, the oven drying method for MC determinations is often too time consuming and wasteful of material. Fortunately there are portable electric moisture meters easily operated by one person which provide rapid assessment of MC. These meters use an electrical property of wood which varies with MC, such as electrical resistance, dielectric constant or radio frequency power loss.

5.3.1 DC-RESISTANCE MOISTURE METERS

Resistance-type meters are offered by several manufacturers but all employ the same principle of operation. The operation of the DC-resistance-type of meter is based on the fact that oven-dry wood is an excellent electrical

insulator; that is, the wood has a very high electrical resistance. The resistance decreases rapidly as the MC of the wood rises towards the fibre saturation point (FSP = 25 to 30% MC) after which point there is very little change in resistance with increases in MC.

A resistance meter is designed to measure the electrical resistance between two points in a piece of wood. The resistance is usually measured between two electrodes or needles which are driven into the wood so that the electrodes are aligned along the grain of the wood. Electrodes are usually mounted on convenient handles which allow them to be driven into and withdrawn from the wood with little effort. For smaller units short electrodes are mounted directly on the meter.



(a)



Figure 5-2

Example of a DC-resistance moisture meter with probe (a). Most meters of this type are calibrated for readings taken with the pins parallel to the grain direction (b).

To take a reading, drive the electrodes into the wood parallel to the grain, wait a second or two for the reading to stabilize and then observe the value on the meter which is normally expressed as percent MC. This value however, should not be assumed to be the MC since both temperature of the wood and the species affect the reading obtained and must be adjusted for accordingly. Whether these adjustments are made internally by the software in the meter or manually, the user needs to be concerned with whether the most appropriate correction factors are being applied.

The temperature of the wood being tested affects the reading given by the meter because at any given MC, the resistance in the wood falls as the temperature increases. Usually the reading given by the meter has been calibrated for a wood temperature of 70 F (21 C) and, if the wood temperature is higher or lower than this, then a correction must be made. It is therefore necessary to know the temperature of the wood being tested and then correction tables can be used to correct the readings. Temperature corrections for both DC-resistance and dielectric moisture meters are presented in Table 5-2.

A convenient method for measuring wood temperature is to insert a temperature sensing probe such as a thermocouple into a hole made by the moisture meter needles and read the temperature directly on the temperature meter.

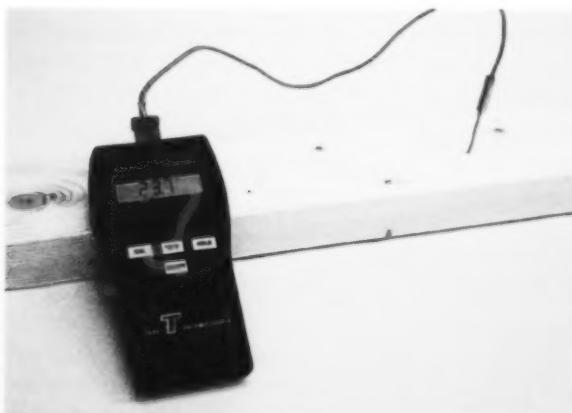


Figure 5-3

Wood temperature can be measured with an electronic thermometer, such as the one shown here, fitted with a thermocouple probe small enough to insert into hole left by moisture meter pin.

The electrical resistance of wood varies with species due to differences in wood structure and electrolyte concentration. Correction factors have been developed for all commercially important softwoods. SPF is a species grouping which is usually processed together and this creates a problem when using a DC-resistance meter since the meter cannot realistically be adjusted for species from board to board. There are two ways to address this. The first is to determine if the species grouping is very heavily weighted to one species and, if so, set the meter for that species and accept any error incurred when measuring other species. The second option is to make use of a composite correction factor assembled specifically for the SPF grouping. In Canada the CLSAB has developed a combined correction factor for SPF that grading associations and many mills apply. For grade stamp lumber this process works well since all parties

employ the same factor and therefore get good agreement. For applications involving value-added products or other situations where a greater degree of accuracy is required, using individual species correction factors is advised.

Individual species correction factors are available from various sources including the meter manufacturers and research institutes such as Forintek. Forintek has a booklet of correction factors available that presents combined adjustments for the effect of both wood temperature and species. As mentioned previously, the onus is on the user to ensure that the most appropriate correction factors are being applied. In some cases this is determined by either the customer or inspection agency setting the standards for the dry lumber. In such instances it is important to follow the procedures set by them to minimize any potential for discrepancy.

Most manufacturers now supply meters complete with user selectable temperature and species factors which then allow a direct reading on the meter display. Some models provide the option to down-load into a data collection system. In these cases, the user should be aware of the source of those corrections and make a judgment as to whether they are the best for the situation. In some cases, the manufacturer will provide a choice of correction factors programmed into the meter or even install several different versions on the same meter.

Pin-type electrodes can be of two main types, insulated and uninsulated. Insulated electrodes can be of any length and their identifying characteristic is that they are coated with non-conductive coating along their length except for the tip or final one-eighth inch (3 mm). The result of this is that the resistance and, therefore the MC is measured only between the electrode tips. As the pair of needles is driven into the wood to varying depths, a MC profile can be developed.

In most instances when wood has recently been removed from a kiln, the moisture in the wood is not evenly distributed. Typically a moisture gradient exists with MC being lowest at the surface and increasing towards the center. This distribution can be accurately detected by using insulated needles long enough to penetrate to mid-thickness of boards. If uninsulated needles are used, the MC indicated will always be that of the wettest wood between the electrodes, at whatever depth this occurs. This is because the electrical resistance is lowest in wet wood, the small electric current flowing between the electrodes will always follow the path of least resistance.

Figure 5-4 shows the pattern of a typical post-drying moisture gradient in SPF dimension lumber. It is easy to see from this that if the pins are driven into the centre of the board, the average MC of the wood will be over-estimated. Conversely, if the pins are placed on or very close to the surface, the average MC will be under-estimated. Forintek has conducted some testing to determine an appropriate depth for testing MC in SPF dimension lumber. The rule of thumb developed is to pin to approximately one-fifth the thickness of the board. For 2-inch dimension lumber this turns out to be approximately 3/8-inch (9.5 mm) in dry-rough lumber, and 5/16-inch (8 mm) in dry-dressed lumber. This recommended pinning depth is less valid for high-temperature, fast-dried wood and is very unreliable for wood that commonly has wet pockets or streaks. This caution obviously applies to high-temperature-dried SPF and to eastern balsam fir and western subalpine fir where wet pockets are a common occurrence.

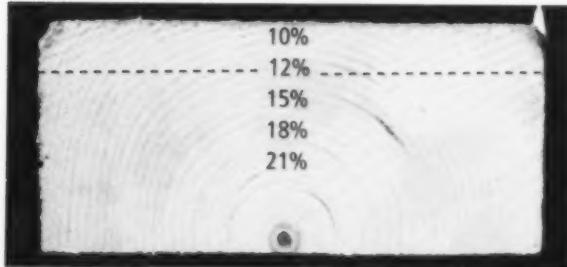


Figure 5-4

Diagram of board end showing normal MC gradient and 1/5th position for average MC.

If the surface of kiln-dried wood has gained moisture from exposure to high humidity, then irrespective of the length, using uninsulated needles (or insulated needles with the paint coating worn off) will always result in a high estimate of MC. If insulated needles had been used, the operator would have seen a high reading as the needles penetrated the surface layers of the wood, but the reading would have fallen, as the uninsulated conducting tips were driven in towards the center of the board. If the surface has been severely re-wetted from rain or melting snow, even the use of insulated pins may not prevent errors.

The range of MC which can be reliably measured with this type of meter is between 6 and 25%. Below 6% the resistance is too high to measure easily, and above 25% there is too little change in resistance to permit accurate measurements. Some meter scales extend beyond 25% but this is only to permit temperature corrections up to the FSP

and do not imply accuracy of readings beyond this limit. This is not an indication, however, that high readings are invalid. They are still an indication that the wood MC is in excess (and probably well in excess) of the desired MC.

Proper operation of the meter should be confirmed by conducting a calibration check every time the meter is to be used such as prior to a hot check or inspection of dried lumber at the planer mill. Many meters have internal calibration checks that verify the workings of the internal components. With a DC-resistance meter it is also advised to conduct a check of the meter, the probe, and cables by testing the resistance measured through the pins on the probe. Figure 5-5 shows how a block with a known resistance can be placed against the pin tips. Given that the meter is set for a standard species and temperature (usually Douglas-fir at 70 F) this test should result in the same meter reading. While holding the resistance block against the pins, the cables can be gently pulled and pushed to see if there are any loose connections. Operators should be alert for other indications of problems with the meter such as it not re-zeroing between readings or readings that are highly erratic.

To avoid errors introduced by end-drying, meter readings with any type of meter should not be taken less than 2 feet (0.6 m) from either end of a board.



Figure 5-5

Calibration of DC-resistance meters can be checked by using a known resistance placed across the tips of the pins.

5.3.2 DIELECTRIC MOISTURE METERS

The term "dielectric" can be used to generally describe a broad range of moisture meters using other electrical properties. Radio-frequency waves are affected by the presence of most materials including wood and water. Dielectric meters operate by measuring capacitance, power loss, or a combination of these two. As a sample is entered into the electric field these electrical properties are affected by the amount of wood and moisture present. By subtracting the effect of the wood from the reading the net effect of the moisture present can be observed. The precise mechanism of operation of these meters is not as apparent as it is with DC-resistance and therefore it is impossible to give a more detailed technical description for the various commercial brands in

use. From an end-users point of view, it is important to understand under what conditions this type of equipment can be employed and what level of accuracy can be expected.

Specific gravity has an effect on the meter reading and this effect is usually accounted for by the meter before providing an estimate of MC. It is important to ensure that the meter is compensating for the appropriate specific gravity for the species being evaluated. As described in Chapters 1 and 2, specific gravity of any species is prone to variation. Meter manufacturers typically use published species average values when developing their correction factors. In some cases it may be necessary to test the specific gravity of the material being processed to determine if it is the same or close to the value programmed within the meter. Most meters provide some means of compensating for species that are either not included within the meter or where the pre-programmed value is not appropriate.

One advantage of a dielectric meter is that it does not damage or physically mark the material in any way. This does make it appealing for applications where pin holes are not acceptable in the end product. The down side of this, however, is that this class of meter cannot provide any specific data on the distribution of moisture within a sample. In some cases, the presence of a moisture gradient may negatively affect the readings from this type of meter. The dielectric field created by the meter is af-



Figure 5-6

Dielectric type moisture meter with extension probe used to obtain MC estimates from boards inside a load of stickered lumber.

fected by material within its range. Tests conducted by Forintek show that when applied to material with a normal post-drying moisture gradient, reasonable estimates of average MC can be obtained. When "non-normal" conditions are encountered, the readings may become less accurate. For example, wood that has become re-wetted on the surface will produce misleading results. Even a thin layer of high-MC material near the surface will elevate the reading on a dielectric meter more than expected and result in an overestimation of the average MC. When sampling wet pocket material the situation is reversed such that the presence of a large wet pocket just below a very dry shell will result in an underestimation of the average MC. These situations should be either avoided or at least taken into consideration when interpreting readings from this type of meter.

Table 5-1

Factors affecting MC estimates made with dielectric meters.

Factor	Impact on Reading
Species (black spruce)	Underestimate MCs below about 12.5%. Overestimate MCs above this level.
Specific Gravity	Within-species variations in specific gravity will affect accuracy. Underestimate MC if specific gravity chosen on meter is more than the actual specific gravity of the wood. Overestimate MC if specific gravity chosen on meter is less than actual specific gravity of the wood.
Moisture Gradient	Reading is affected by surface moisture (either higher or lower than average MC for cross section)
Wood Temperature	Meter reading is increased with increasing wood temperature (see Table 5-2).
Condition of Wood Surface	Underestimate MC on rough vs. planed surface.
Width of Board	Underestimate MC when board width is less than width of sensor head.

As with DC-resistance, dielectric meters are affected by a number of physical and environmental factors. Table 5-1 provides a summary of factors which have been found to affect a commonly employed dielectric meter. Although it is impossible to correct for all of these factors it is often possible to test in situations where these factors do not affect the reading. Another approach is to standardize testing procedures so that readings taken at one time can be compared to those taken either before or after.

As shown below, dielectric meter readings are also affected by wood temperature. Tests conducted by Forintek on one particular brand of meter have shown that the magnitude of this temperature effect is roughly half of that experienced with DC-resistance meters. Although minor fluctuations in wood temperature may not be a concern for this meter type, there are situations where temperature compensation should be taken into account. This would include the evaluation of extremely cold or warm material such as winter-stored lumber or material recently removed from (or still in) the kiln. Table 5-2 lists the temperature correction developed by Forintek for the "Wagner" brand of dielectric meter. A report is available providing more detail on the effects of temperature and other variables on meter reading.

As shown in Figure 5-6, dielectric meters can be fitted with a remote probe that allows MC measurements to be obtained on boards within a stickered package of lumber. This makes it possible to obtain a larger, more representative range of samples. Care must be taken, however, to ensure that the sensor head is well centred over a board before a reading is recorded. If the sensor head is not centred and is either bridging two boards or partly exposed to an air space, the meter readings will be lower. All of the factors listed above that affect dielectric meter readings are relevant whether using the meter on its own or with a remote probe.

Table 5-2

Effect of wood temperature on dielectric and DC-resistance meter readings. (Forintek study results)

Figure 5-7

Checking calibration on a dielectric moisture meter with a block that provides a known response.



As with DC-resistance meters, calibration must be checked on a regular basis. Again, an internal calibration check may verify the internal components but the best check is some sort of external reference block. This cannot be a block of wood as the MC of any piece of wood will vary over time. Manufacturers often supply or make available as an option a composite block with known and stable dielectric properties (see Figure 5-7). The sensor pad, either on the meter or a remote probe, can then be placed on this reference block and the reading on the meter verified. This only takes a few seconds and should be done prior to every application of the meter.

5.3.3 APPLICATION AND INTERPRETATION OF RESULTS FROM HANDHELD MOISTURE METERS

The specific technical guidelines mentioned above should be taken into account when using either of the two major classes of handheld moisture meters. The following general comments are relevant to the interpretation of results from either type of meter.

Various studies at Forintek and elsewhere have shown that dielectric and DC-resistance meters can achieve similar levels of accuracy, given that they are employed

Temperature Correction at a Wood Temperature of (°C)

	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°
Dielectric	+2.5	+2.0	+1.5	+1.1	+0.6	+0.1	-0.4	-0.9	-1.3	-1.8
DC-resistance	+5.2	+4.3	+3.3	+2.4	+1.3	+0.3	-0.8	-1.9	-3.1	-4.3

correctly and the appropriate correction factors applied. As with DC-resistance, dielectric meters are designed for use on material below the FSP. These meters tend to be more stable when measuring lower MC material; i.e., under 10%. For both meter types the meter readings will be more accurate toward the lower end of their range. Individual readings in excess of 19% will have a wider margin of error associated with them. Under the conditions described above, both classes of meters can generally attain an accuracy of plus or minus 1 to 2% MC.

All moisture meters exhibit some variation in error from sample to sample. This is due to the varying properties of wood such as specific gravity and extractive content. Over a large population, these effects should average out. Therefore, a way of achieving better estimates of MC for a charge or group of material is to look at population statistics rather than individual readings. Parameters such as average, standard deviation and percentage of material within specific MC ranges are useful ways of evaluating and comparing batches of material. The following example (Table 5-3) shows how a good estimate of the average MC for a relatively small number of samples can be achieved. In this case, the moisture meter was able to achieve an estimate of the average MC for the group with an error of less than 0.5% MC from the actual average oven-dry MC. Although individual board readings show larger errors, the positives and negatives often average out in your favour.

Although neither meter type is recommended for use on material over the FSP that does not mean that high readings are totally unreliable. In most applications of a meter the primary concern is whether the material falls within or outside of the desired final MC range. The vast majority of products require a final MC of 19% or less. Therefore, readings below this level can be relied on as a good indication that the material is dry. Although read-

ings above this level are less accurate they are still a good indication that the material is wetter than the acceptable limit. Again, if we consider that estimation errors happen in both directions, then the percentage of "wets" for a large group will generally be a good estimate of that particular parameter.

The guidelines mentioned above are appropriate to most sampling situations, however, when dealing with material prone to wet pockets there are some precautions. Figure 5-8 shows histograms of final MC for SPF mixtures both with and without wetwood material. The sample group without wetwood displays a "normal" distribution pattern and for this pattern, the above advice on use of statistics is relevant. The second histogram reveals a skewed distribution due to the presence of wets caused by wetwood material. For this material, statistics such as average and standard deviation are less useful. In this situation it may be better to look at percentage of material in excess of a certain MC. Since over-drying is also a concern when handling material with wets, it may also be useful to look at percentage of material within a pre-established "acceptable" range and then present statistics on percentage of material "over-dried" as well as "wet".

5.4 IN-LINE MOISTURE METERS FOR DRY LUMBER

In-line moisture meters have been available for many years but have only recently become common in planer mills of SPF operations. Most modern mills are equipped with an in-line meter at the planer mill to measure MC of each piece of kiln-dried lumber. The value and uses of these data is the subject of this section.

The technology employed for in-line meters is similar to

Table 5-3

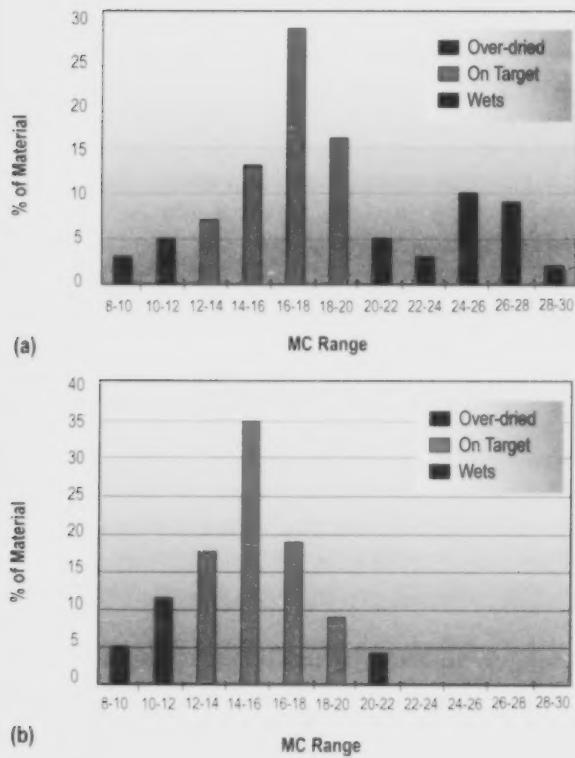
Example of how averaging a group of meter readings can result in a good estimate of the average MC even though individual meter readings may have larger errors.

	Individual Meter Readings										Average
	18.5	17.9	16.2	13.4	15.4	18.1	16.9	17.1	16.4	16.1	
Oven-dry MC											16.6
Moisture Meter MC Estimate	17.2	18.1	15.6	13.6	16.8	19.8	15.8	17.5	16	16.9	16.7
Error (ODMC-MeterMC)	+1.3	-0.2	+0.6	-0.2	-1.4	-1.7	+1.1	-0.4	+0.4	-0.8	

Note: This example is relevant to any meter type and assumes that readings have been corrected for the effect of temperature, species, and other factors mentioned in the previous sections.

Figure 5-8

Histograms showing both a "normal" (part b) and "non-normal" (part a) distribution of final MC. Both diagrams also identify material designated as "over-dried" or "wets".



the handheld dielectric meters. The size and power of the sensing plates are much greater than in the handheld versions, but many of the factors affecting performance of the handheld meters also affect the in-line meters. Moisture gradient, wood temperature and specific gravity are all factors which need to be either corrected for or considered when interpreting readings from these systems.

In-line moisture meters provide an opportunity to collect detailed information on final MC that is not attainable through other means. The board-by-board MC data can be used in a number of ways to improve a drying operation.

The obvious application of an in-line meter is to assure that all material meets the MC specification of the customer. These meters are often installed downstream from the planer and are used to assure that the MC distribution of the material meets the requirements. When

excess amounts of "wets" are encountered material may be rejected or downgraded and typically, subsequent kiln charges are dried on a longer schedule. This is an important function and advantage of this type of equipment but, if this is the only use, there are some opportunities being overlooked.

Analysis of the data from the in-line moisture meter can help reveal problems with drying schedules or equipment issues. One way of doing this is to "map" the final MC distribution within the kiln. Figure 5-9 shows an example of how the final MC data can be summarized to reveal variations in final MC related to location within the kiln. As can be seen, there is one zone within the kiln that is wetter than the rest of the load. This should suggest to the kiln operator that there may be a problem in the kiln. The problem may be related to airflow or temperature distribution. By alerting the operator in this manner the problem can be addressed before it persists long enough to cause a problem for customers. To accomplish this final MC data must be summarized and provided back to the kiln operator. By "closing the loop" in this manner, the kiln operator can measure the impact of other variables such as changes in the drying schedule or changes to the pre-sorting operations. In-line meters should be considered as the number one quality control and process improvement tool for most SPF drying operations.

In-line meters also offer the opportunity to implement a re-drying program. Re-drying is discussed in detail in Chapters 4 and 15. The only way, however, to implement such a program is with an in-line meter. For this type of application the meter must be installed prior to the planer along with some means of physically separating the "wets" in the rough condition. In this manner they can be returned to the kiln (or some other drying process) for re-drying.

5.5 CORRELATING READINGS FROM DIFFERENT METERS

Due to the wide range of factors that affect each of the different electrical methods for estimating MC it is inevitable that test results will never be directly comparable. This is true whether different meter types are being used or even if the same type of meter is used at different stages in the production process. The best practice is to standardize the test procedures, accept the fact that different meters will result in different MC estimates, and develop a means to correlate among them. Techniques and an example on how to develop a correlation are presented in Chapter 14. Before proceeding, however, a

Top of Load

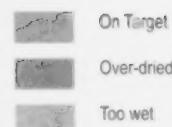
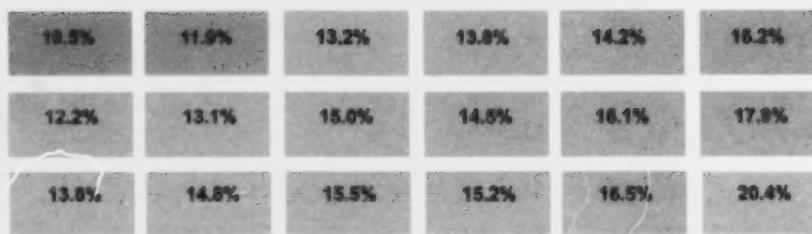


Figure 5-9

Presentation of final MC data from an in-line meter to "map" or "reconstruct" a kiln load (side view). Colours indicate areas of kiln contributing to over-dried or "wets".

decision must be made on what is the base line or standard for any correlations to be developed. This could be oven-dry MC, but in most cases will be a specific meter type with specified correction factors. This will usually be the meter that the mill has had the most experience with and/or the one in which they have developed the most confidence.

Top of Load						
10.5%	11.9%	13.2%	13.8%	14.2%	16.2%	On Target
						Over-dried
12.2%	13.1%	15.0%	14.5%	16.1%	17.9%	Too wet
13.8%	14.8%	15.5%	15.2%	16.5%	20.4%	

Figure 5-9

Presentation of final MC data from an in-line meter to "map" or "reconstruct" a kiln load (side view). Colours indicate areas of kiln contributing to over-dried or "wets".

decision must be made on what is the base line or standard for any correlations to be developed. This could be oven-dry MC, but in most cases will be a specific meter type with specified correction factors. This will usually be the meter that the mill has had the most experience with and/or the one in which they have developed the most confidence.

PHYSICAL ELEMENTS OF DRYING

The effect of temperature, humidity and air circulation on the mechanism of moisture movement in wood is a subject of considerable depth and complexity and only a short outline of the basic principles is attempted in this manual.

6.1 WATER IN WOOD

Descriptions were provided in earlier chapters of the various forms of water in wood; free water in both the liquid and vapour form and bound water. In the drying of lumber these forms of water move to the surface by quite different mechanisms and by different flow paths. Depending on the conditions which exist in the wood, water may be converted from one form to another during this migration. For example, green lumber at ordinary temperatures contains about 30% of its dry weight as bound water, a negligible quantity of water vapour, and the remainder of the moisture as free water. For a wood like spruce, with an initial moisture content (MC) of about 60%, roughly half the moisture will be bound water and half free water. For subalpine fir, with 90% initial MC, there will be twice as much free water as bound water. In drying, the free water of the surface layers is the first to be removed. As a result, the moisture in the surface layers soon consists almost entirely of bound water, with a very small quantity of water vapour. Moisture moving from the core is converted, in turn, to bound water and then to water vapour, in which form it escapes.

6.1.1 FREE WATER MOVEMENT

Free water in wood moves in response to capillary forces created by the evaporation of water from the surface cells. These forces exert a pull on the free water in zones below the surface. The most important factor affecting capillary flow is the permeability of the wood. Capillarity requires the least energy and is the most rapid form of the various flow mechanisms. This is the major reason why moisture-laden permeable sapwood normally dries at a more rapid rate than heartwood.

Capillary flow is at least 50 times faster in the direction of

the grain than across it, because bordered pits or other obstructions (which are bottlenecks, even in permeable woods) are encountered much less frequently.

Free water movement can only occur where free water is present; that is, above the FSP. But it also requires the presence of enough moisture to provide a continuity of water reaching from the surface or evaporating zone to the zones below. Consequently it is faster at higher MC.

A further factor affecting capillary movement is the wood temperature. At higher wood temperatures the viscosity of water is reduced so that under a given capillary pull, the water will flow more rapidly. A rise of wood temperature from 70 F (21 C) to 210 F (99 C) reduces viscosity by a factor of three.

6.1.2 MASS FLOW

Another drying process is mass flow during high temperature drying. When lumber at a MC greater than the FSP is heated above the boiling point of water, some of the water is converted to steam at a pressure above atmospheric. If the lumber is of a permeable wood, the steam escapes due to the pressure differential and the lumber dries. If the lumber is of an impermeable wood, drying can take place only by diffusion, although at this temperature it is a fairly rapid process. Because steam generated in wood heated above boiling point may have enough pressure to split wood, the use of high temperatures to dry an impermeable wood will usually result in severe degrade and should therefore be avoided. High temperatures are effective and safe on more permeable species such as jack pine and some spruce species.

6.1.3 VAPOUR DIFFUSION

Water vapour moves by diffusion. In this process, molecules move in a random manner in all directions. If a high concentration of molecules occurs in one area and a low concentration of molecules occurs in another, more molecules will leave the high-concentration area than will enter it. If the molecules moving are water molecules, then the MC of the wood will be reduced. Similarly, if

molecules are being captured, condensed or removed from another area, more molecules will diffuse in than out, and there will be a net movement in that direction. The rate of vapour diffusion is thus proportional to the difference in concentration of diffusing water molecules or, more precisely, is proportional to the difference in vapour pressure. The vapour pressure within moist wood increases with increasing MC up to the FSP; thus, while drying is taking place a vapour pressure gradient will exist from the zone within the wood which is at or above the FSP to the wood surface. There will be no significant vapour pressure gradient within the zone that is above the FSP. This means that within the zone above the FSP, no significant vapour movement is taking place. Since there must be a continuous flow path available to permit vapour to diffuse from one zone to another, pure vapour diffusion is only effective in permeable wood.

Permeability results from the presence of connecting pit openings between wood cells. It is not related to hardness or strength, but only to the openness of these connecting passages. Liquids and gases move through permeable wood at rates which permit rapid drying. In impermeable wood, most or all passages are blocked, so that movement of liquids and gases is obstructed. Vapour diffusion must then operate in conjunction with bound water diffusion. The sapwood of SPF species is permeable, but the heartwood of most softwoods is much less so. Heartwood of subalpine and balsam fir is impermeable, that of lodgepole and jack pine is semi-permeable, white and red spruce may be considered semi-permeable to permeable, and black spruce may be considered semi-permeable to impermeable. The "yellow spruce" portion of black spruce would definitely fall into the impermeable category.

6.1.4 BOUND WATER DIFFUSION

The movement of bound water through the cell walls is also a diffusion process. As in vapour diffusion, there are fewer water molecules leaving the drier sites and more leaving the wetter sites. Consequently, there is a general migration from the wet to the dry parts of the wood. Since the wood surface is usually driest because of evaporation, there is a migration from core to surface and a moisture gradient exists.

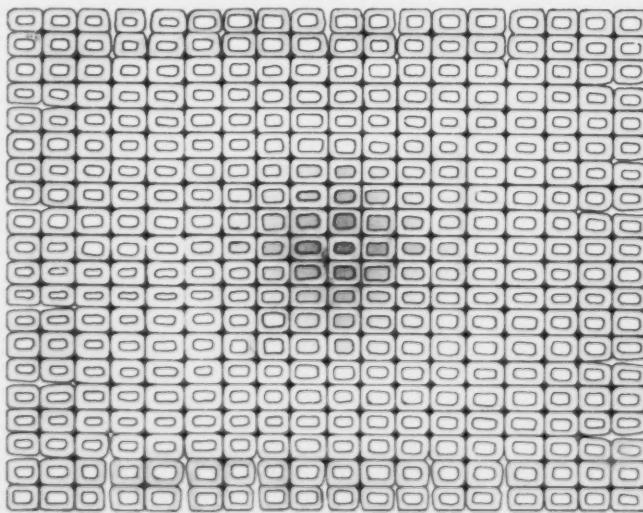
The force responsible for bound water diffusion is the same as for vapour diffusion, the vapour-pressure gradient. Bound water diffusion is a much slower process than vapour diffusion even though driven by the same force.

6.1.5 COMBINED BOUND WATER AND VAPOUR DIFFUSION

During drying neither bound water nor vapour diffusion acts alone. In moving from the core to the surface of the wood most moisture passes in sequence through the cell walls by bound water diffusion, evaporates into the cell lumen, passes across it by vapour diffusion, is absorbed by the next cell wall, passes through by bound water diffusion, and so on until the wood surface is reached. Figure 6-1 shows how this sequence may exist within a piece of wood toward the middle stages of drying.

Figure 6-1

A cross section of wood cells from the surface below FSP toward the core with cells containing both bound and free water.



When drying takes place from the ends of lumber the migrating moisture must pass through fewer cell walls, and the greater part of its migration is through the cell cavities by the much faster process of vapour diffusion. Consequently, drying through the ends is much faster than drying through the sides of a piece. Since dense wood contains a much higher ratio of cell wall to cell lumen than low density (light) wood, and since bound water movement through the cell walls is slower, the rate of drying below the FSP in dense woods is much slower than in light woods. The greater resistance to drying of dense wood can result in a much greater moisture gradient being formed and much greater shrinkage stresses being developed so that the possibility of degrade in dense hardwoods is much more than in most softwoods including all SPF species.

6.2 MOISTURE GRADIENTS DURING DRYING

Water in wood normally moves from higher to lower zones of MC. This fact supports the common statement that "wood dries from the outside in", which means that the surface of the wood must be drier than the interior if moisture is to be removed. Drying can be broken down into two phases: movement of water from the interior to the surface of wood, and removal of water from the surface. Moisture moves to the surface more slowly in heartwood than in sapwood, primarily because extractives plug the pits of heartwood. In drying, the surface fibres of heartwood of most species reach moisture equilibrium with the surrounding air soon after drying begins. This is the beginning of the development of a typical moisture gradient as shown in Figure 6-2. In a drying process the MC in the inner portion of the board will be higher than the outer portion. Figure 6-2 also compares the differences in moisture gradient when green wood is exposed to high EMC and low EMC conditions. The surface fibres of sapwood also tend to reach moisture equilibrium with the surrounding air if the air circulation is fast enough to evaporate moisture from the surface as quickly as it reaches the surface. If the air circulation is too slow, a longer time is required for the surface of sapwood boards to reach moisture equilibrium. This is one reason why air circulation is so important, but especially during the early stages of kiln drying.

Water moves through wood as liquid or vapour through several kinds of passageways. These are the cavities of fibres, ray cells, pit chambers and their pit membrane openings, resin ducts of certain softwoods, and other intercellular spaces. Most water lost by wood during drying moves through cell cavities and pits. It moves in these passageways in all directions, both along and across the grain. In general, lower density species dry faster than heavier species because their structure contains more openings per unit volume.

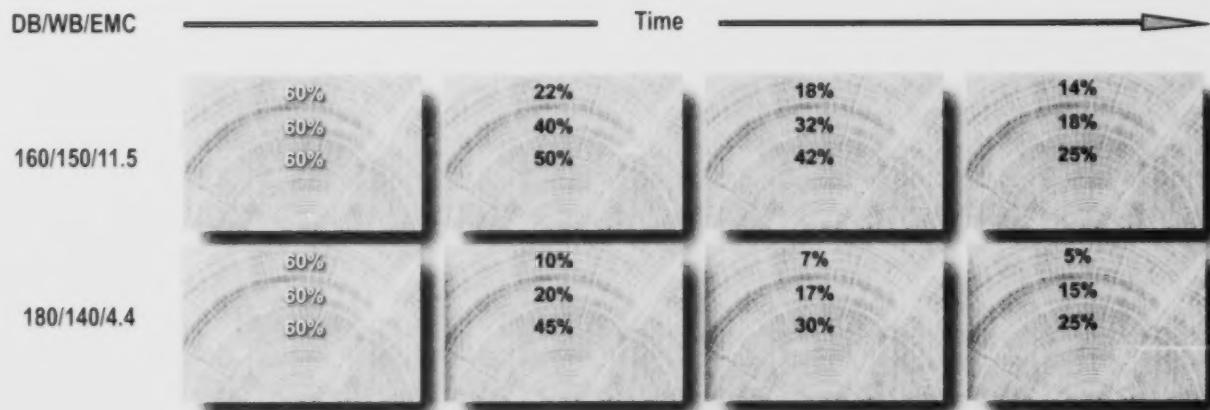
When wood is drying, several forces may be acting simultaneously to move water:

1. Capillary action causes free water to flow through the cell cavities and pits.
2. Differences in RH cause water vapour to move through the cell cavities by diffusion, which moves water from areas of high to areas of low RH. Cell walls are the source of water vapour; that is, water evaporates from the cell walls into the cell cavities.
3. Differences in MC cause bound water to move through the cell walls by diffusion, which moves water from areas of high to areas of low MC. Generally, any water molecule that moves through wood by diffusion moves through both cell walls and cell cavities. Water may evaporate from a cell wall into a cell cavity, move across the cell cavity, be reabsorbed on the opposite cell wall, move through the cell wall by diffusion, and so on until it reaches the surface of the board.

Figure 6-2

Impact of drying conditions on severity of moisture gradient created during the early to middle stages of drying. Once the shell falls below the FSP the magnitude of the MC difference between the shell and core will be directly related to the stress level created. The lower example depicts a harsher drying environment and the impact on moisture gradient can be seen.

When green wood starts to dry, evaporation of water from the surface cells sets up capillary forces that exert a pull on the free water in the wood beneath the surface, and flow results. This is similar to the movement of water in a wick. Much free water in sapwood moves in this way. In comparison to diffusion, capillary movement is fast.



Longitudinal diffusion is about 10 to 15 times faster than lateral (radial or tangential) diffusion. Although longitudinal diffusion is faster than lateral diffusion, it is of practical importance only in short items. Most lumber products are so much longer than they are thick that the majority of water removed during drying goes through the thickness direction, leaving from the wide face of the board. Radial diffusion, perpendicular to the growth rings, is somewhat faster than tangential diffusion, parallel to the rings. This explains why flatsawn lumber dries faster than quartersawn lumber. In lumber where width and thickness are not greatly different, such as in squares, significant drying occurs in both the thickness and width directions.

The rate of diffusion depends to a large extent upon the permeability of the cell walls and their thickness. Thus permeable species dry faster than impermeable ones, and the rate of diffusion decreases as the specific gravity increases.

Because moisture moves more freely in sapwood than heartwood, both by diffusion and by capillary flow, sapwood generally dries faster than heartwood under the same drying conditions. The heartwood of many species, however, is lower in MC than sapwood, and may reach the desired final MC sooner.

6.3 TEMPERATURE

Heat is the source from which the water molecules in wood acquire the energy necessary for evaporation to take place, and the rate of evaporation is dependent upon both the amount of energy supplied per unit time and the ability of the heating medium (air) to absorb moisture. Drying progresses inward from the surface of the board and, if temperature is constant, the rate of evaporation will gradually decrease as the supply of moisture in the wood is diminished and as the vapour pressure of the air is increased. Therefore, to maintain a steady drying rate, the water molecules in the wood must acquire additional energy, or the vapour pressure of the kiln atmosphere must be reduced. This is achieved by either increasing the temperature (more energy) or reducing the RH (lower vapour pressure). In order to obtain the same rate of moisture movement at 120 F as at 160°F (49°C and 71°C), a much lower humidity would be required, such that the reduction in heat energy is compensated for by the increased moisture affinity of the drier air.

In discussing temperature, it should be borne in mind that the dry-bulb kiln temperature during the drying process is higher than the temperature of the lumber. When

lumber contains free water, the temperature of the wood is approximately the same as that of the wet-bulb, and it will stay close to this temperature as long as there is sufficient moisture movement to keep the surface moist. As the supply of free water diminishes and the MC of the wood approaches fibre saturation point (FSP), the temperature of the wood begins to rise towards the dry-bulb temperature. As the MC falls below the FSP, the wood will quickly approach the dry-bulb temperature.

6.4 TEMPERATURE DROP ACROSS THE LOAD (TDAL)

As air passes through the lumber pile, it gives up heat to the wet wood, becomes cooler and cannot heat the lumber near the exit side as much as that on the entry side. There is therefore a temperature gradient or drop across the load (TDAL) with the higher temperature on the entry side. This gradient is not regular, since a larger portion of the heat is lost in the first part of the load. Since more heat is transferred from the air to the wood in the first portion of the load, this wood dries faster and, consequently, at any stage in the drying process, its MC is lower than the remainder.

This non-uniform MC profile along the air pathway worsens as the distance that the air has to travel increases, that is, the width of the lumber pile is increased. In order to minimize the effects of the TDAL, it is necessary to establish regular fan reversal periods and try to keep the air pathway as short (narrow) as possible.

Rate of airflow through the load will also affect the TDAL. Slower moving air will spend more time within the load on each pass and the temperature drop will be greater. Therefore, one means of reducing the TDAL and producing a more uniform drying environment, especially during the early stages of drying, is to increase the rate of airflow.

In recent years TDAL has been used by kiln operators and kiln controller manufacturers as an indirect measure of the rate or progress of drying. It has been used as an indicator of when to make changes to the kiln schedules, when to alter (usually lower) kiln air velocities and when a load is dry.

6.5 RELATIVE HUMIDITY (RH) AND EQUILIBRIUM MOISTURE CONTENT (EMC)

As used in lumber drying, RH is a measure of the "amount" of water vapour in the air, expressed as a percentage of the total "amount" contained in saturated air at a given temperature and pressure. For example, when

air is saturated (100% RH) at 140 F (60 C) and atmospheric pressure, it holds 131 grams of moisture per cubic meter. If only 72g/m³ are present at this temperature and pressure, the RH is 55% (72 ÷ 131). Increasing the temperature of the air increases its capacity for holding moisture. More moisture is required to saturate the air if the temperature is raised. Increasing the temperature of the air without adding more moisture will cause the RH to decrease. For example, if the air with a RH of 90% at 20 C is heated to 70 C, its RH drops to 7% because of the increased moisture-holding capacity of the hotter air. The effect of temperature increase on RH is shown in Table 6-1 for a wider range of temperature and RH conditions.

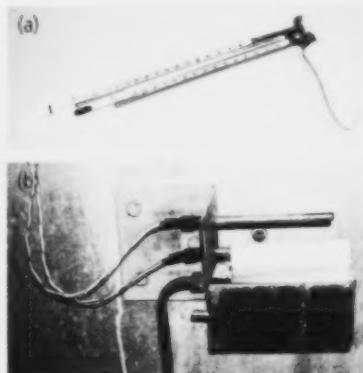
In kiln drying, RH is often determined by use of some form of dry- and wet-bulb psychrometer (Figure 6-3).

Table 6-1
Effect of raising temperature on the relative humidity of a body of air when no moisture is added.

Initial temperature (°C)	Initial RH	New RH (%) when air is heated by:				
		10°C	20°C	30°C	50°C	70°C
-20	50%	19	8	4	<2	<2
	90%	36	15	8	4	<2
0	50%	25	13	7	2	<2
	90%	45	24	13	4	<2
+20	50%	27	16	9	4	<2
	90%	50	29	17	7	3

Figure 6-3

RH and EMC can be determined by measuring wet- and dry-bulb temperatures using either a sling psychrometer (a) or a traditional dry-bulb/wet-bulb sensor placed in a moving air stream (b).



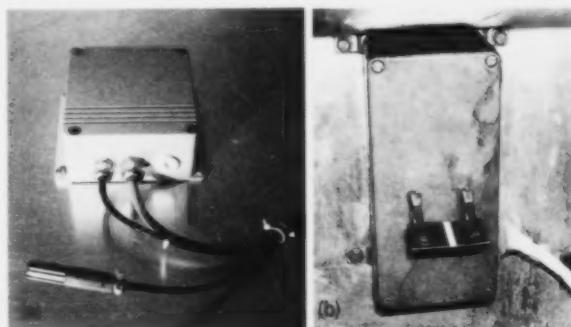
A psychrometer consists of two similar thermometers exposed to the circulating air; the bulb of one of them, the wet-bulb thermometer, is surrounded by a clean cotton wick which is kept wet by a small reservoir of water. Evaporation from the wick creates a cooling effect and therefore shows a lower temperature than the

dry-bulb thermometer. The difference between the two thermometer readings is called the wet-bulb depression, which is directly related to the RH of the air. The greater the rate of evaporation from the wet-bulb wick, the greater is the cooling effect and this varies directly with the amount of moisture in the air, such that a greater wet-bulb depression is equivalent to a lower RH.

Direct measuring RH devices are now available for use in kilns. As shown in Figure 6-4, these are stand alone devices which do not require a water supply or wick and require only occasional attention or maintenance. The most reliable method for measuring kiln conditions is still a wet- and dry-bulb system and, therefore, it is usually used as the reference when calibrating other systems such as electronic RH sensors. There are other systems available for calibrating these devices but they are usually more expensive, complicated and not required for a kiln drying situation.

Figure 6-4

RH and EMC can also be determined through the use of an electronic RH sensor (a) or an EMC sensor such as this paper wafer (b) held between two electrodes.



The EMC of lumber is determined largely by the RH in a kiln. Therefore, to avoid excessive surface shrinkage and consequent drying defects, the RH should be kept at a high value. On the other hand, high relative humidities reduce the difference in vapour pressure between the dry- and wet-bulb temperatures and, consequently, reduces the rate of drying. As the kiln humidity increases due to evaporation from the lumber, provision must be made to remove the excess moisture. This is usually done by discharging some of the kiln air through roof-mounted vents.

EMC is usually determined through the measurement of wet- and dry-bulb temperatures and the use of charts such as those shown in Table 3-4 and, in more detail, in Appendix II. There are some systems, such as that

shown in Figure 6-4 which are available for measuring EMC. This system measures electrical resistance of a thin fibrous wafer which quickly picks up or loses moisture in relation to the conditions around it.

6.6 AIR CIRCULATION

To perform effective drying, a uniform movement of air is necessary to carry heat to lumber and to carry evaporated moisture away. This circulating air must pass over the surface of the boards being dried. Any air that misses a pile of lumber accomplishes no drying.

In most kilns, air flow is the means by which heat is transferred from the heating system to the wood. As air flows over the surface a temperature gradient between the air and the wood (with the air being hotter) causes an exchange of heat between the two and the wood's temperature will increase. The effectiveness of this heat transfer is affected by air flow. At low flow rates, there is a drag effect near the surface which produces a thin layer of dead air and slows down the rate of heat transfer. By increasing air flow, the air patterns near the surface become turbulent and heat transfer rates increase. The critical level of air flow for heat transfer is about 250 to 300 fpm (1.3 to 1.5 m/sec). The majority of modern kilns for softwood drying operate at air flow levels in excess of this and therefore, this is not usually a limiting factor in determining drying rate or time.

Since air is cooled and becomes wetter as it picks up moisture, its ability to dry becomes progressively less as it passes through a load. By increasing the air velocity, the lumber near the exit side of a load receives hotter, drier air than it otherwise would. Not only will this result in faster drying of the lumber at the exit side, increasing the average rate of drying and reducing the drying time, but it will also result in higher surface transfer rates and more uniform drying of a load. These advantages must be measured against the increased cost of power to attain the greater air velocities.

At the beginning of drying, a considerable amount of water is being evaporated and, as a result, the drop in air temperature across a load is very high, and the humidity of the air increases almost to the point of saturation. Under these conditions, for rapid drying the air velocity should be high. On the other hand, when the surface of the lumber has dried below the FSP, the rate of evaporation is reduced. Under these conditions, a much reduced air velocity is acceptable. Figure 6-5 shows the impact of airflow on drying rate for material at different MC levels.

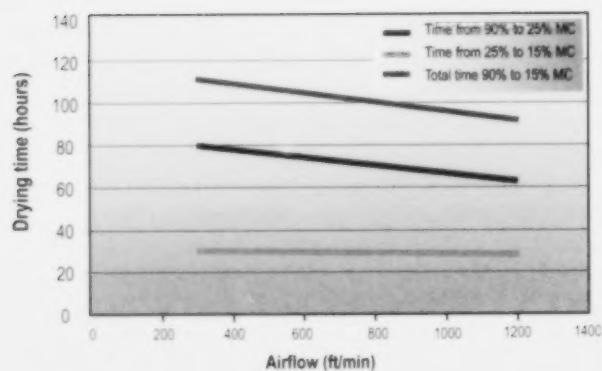


Figure 6-5

Impact of level of airflow on drying rate for SPF lumber above and below the fibre saturation point.

The concept of using adjustable speed drive controls for kiln fans was introduced to the industry in the mid-1980s. In principle, the concept is based on the fact that when free water is available at the surface of lumber being dried, the drying rate is limited only by the rate of evaporation from these surfaces. Therefore, higher air velocity will pass a larger mass or volume of air over the lumber surfaces and evaporate more water.

As the surfaces dry below the FSP, the rate of drying becomes limited by the diffusion of water through the wood cell walls. As this occurs the drying rate is said to be diffusion limited, and is not appreciably improved by higher air flow.

Newer kiln controls track MC in the lumber being dried using a variety of indirect measures including TDAL, weight sensing and in-kiln resistance or capacitance probes. After a history of schedules has been developed it is possible to program the instrument to produce kiln fan speed control as a function of MC. This makes the fan speed control interactive with the drying process. The main incentive to reduce air flow later in drying is to save electrical energy. The application of variable speed drives and impact on energy consumption are described further in Chapter 20.

Hot air is less dense than cooler air and is therefore easier to circulate. The result is that fans that may be highly loaded at start-up will have extra capacity when the air is heated. If a variable speed drive is used, this phenomenon can be used to advantage. By starting the fans at a lower speed the maximum load on the motor can then be achieved once the kiln air is heated. This will result in a faster air flow and reduced drying time.

DRYING SYSTEMS

Lumber drying equipment has diversified considerably both in terms of operating systems and scale of equipment. Drying demands have also diversified and the combined effect is, that for most applications, there are many decisions to be made in making a final selection on a new facility. This chapter will provide a brief overview of the various drying technologies available and their relevance to the SPF industry. The majority of kilns currently in use in this industry are of the "heat-and-vent" variety, therefore, more detail will be provided on them in the next chapter.

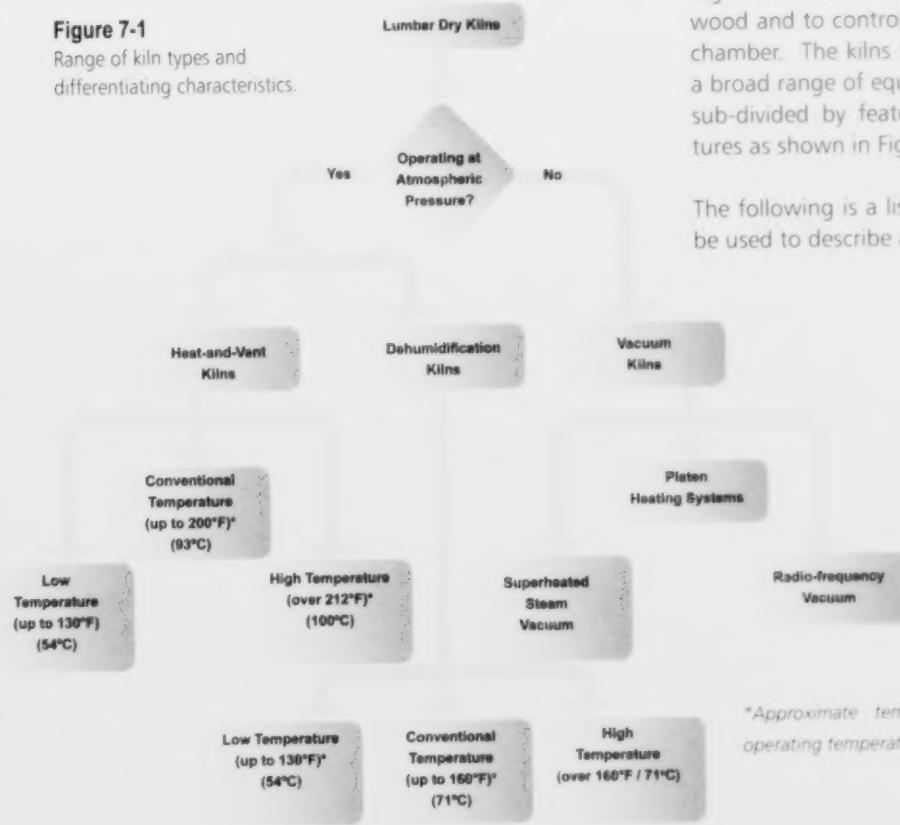
Figure 7-1 is a flowchart showing the range of drying systems available and how they relate to each other. The majority of dry kilns in use operate at atmospheric pressure under controlled conditions of temperature, humidity and airflow. Operating temperatures and installed

features may vary but all of these systems basically dry lumber in the same manner. All things being equal a dehumidification kiln drying at 150 F with a depression of 20 F will dry in exactly the same manner as a conventional kiln maintaining the same conditions. In practice, however, the inherent characteristics of each technology may make it more or less suited than another system when the specific requirements of an application are considered.

7.1 HEAT-AND-VENT KILNS

Heat-and-vent (conventional) drying is by far the most widely used technology in Canadian SPF lumber drying operations. The majority of kilns in service and currently being sold fall into this broad category. The term "heat-and-vent" aptly describes how these kilns operate. Heat provides the energy to dry the material and venting is regulated to exhaust the moisture extracted from the wood and to control relative humidity (RH) levels in the chamber. The kilns that comprise this category feature a broad range of equipment options and can be further sub-divided by features including operating temperatures as shown in Figure 7-1.

The following is a list of features or capacities that can be used to describe a kiln falling into this category.



- Operating Temperature
 - Low temperature [up to 130 F (54 C)]
 - Conventional temperature [up to 200 F (93 C)]
 - High temperature [maximum operating temperature over 212 F (100 C)]
- Heating System
 - Hot water
 - Steam (low or high pressure)
 - Hot oil
 - Direct-fired
 - Indirect-fired
- Energy Sources
 - Fossil fuels
 - Wood residue
- Loading Arrangement
 - Track loaded
 - Package loaded (also referred to as side-loading)
- Fan arrangement
 - Line shaft
 - Cross shaft
 - Single pass
 - Double pass
- Options
 - Steam or water sprays for humidification
 - Variable air flow
 - In-kiln top restraint

More detail on each of these features is presented in Chapter 8.

Figure 7-2

In heat-and-vent kilns, roof or wall vents are used both to evacuate warm, humid air and to introduce cool, relatively dry air.



7.2 DEHUMIDIFICATION DRY KILNS

Dehumidification (DH) kilns dry lumber in the same manner as heat-and-vent kilns by operating at atmospheric pressure and maintaining pre-set levels of temperature and RH. As shown in Figure 7-1, DH kilns can also be designated by the operating temperature they are able to attain. Where DH kilns differ from heat-and-vent kilns is in how they achieve the dry-bulb and wet-bulb temperature requirements. In a DH kiln a heat pump is used to both remove moisture from the kiln air and to supply heat. Figure 7-3 is a schematic of a typical DH arrangement.

In a DH kiln a compressor charged with a refrigerant is situated so that kiln air can be passed first over the cold evaporator coils and then over the hot condensing coils. If the temperature of the "cold" coils is below the dew point of the air stream, moisture will be condensed on their surface. Energy from both the sensible heat and latent heat of evaporation are captured by the refrigerant. The refrigerant is then passed through the next stages of the heat pump and eventually to the "hot" condensing coils. These coils will be hotter than the cooled and dehumidified kiln air and as that air is passed over them its temperature is raised through the addition of sensible heat. In this respect these systems are more energy efficient than the heat-and-vent principle described in the previous section. The overall energy balance for a given application and the cost of various fuels will determine if this type of system will be more cost efficient. Invariably it will be the economic considerations that drive the choice of this, or any other, drying system.

The operating temperature limits of a heat pump are determined by the type of refrigerant used. Earlier systems used either R12 or R22 and were limited to operating temperatures of approximately 120 to 130 F (49 to 54 C) or 150° to 160 F (66 to 71 C) depending on when they were built. Environmental concerns over the use of those refrigerants have limited their use and most new systems being installed are using newer, more environmentally acceptable refrigerants. Older systems can still be serviced but as time goes on, supplies of the earlier refrigerants will disappear or become extremely limited. For existing systems, it may be possible to convert to one of the newer refrigerants but only the kiln manufacturer or a heat pump specialist could make this determination.

The dehumidification process is more energy efficient than other means of dehumidifying and heating an air stream. When considering just the operation of the heat pump, the coefficient of performance will be from 2.0 to 4.5. This means the system is able to recapture and transfer back to the air stream up to 4.5 times as much

Basic dehumidification drying principle

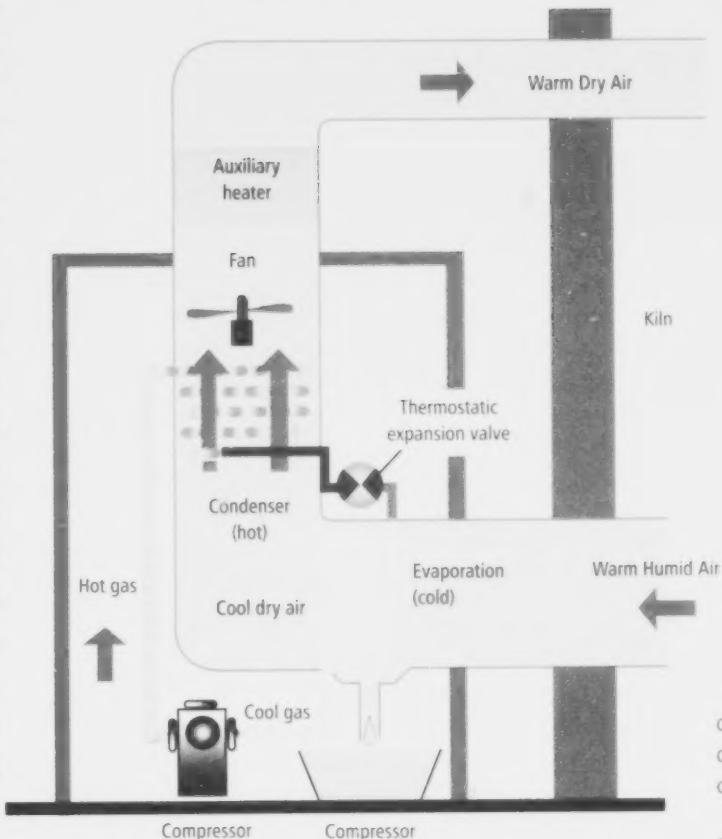


Figure 7-3

Dehumidification kilns use a heat pump system to extract moisture from the warm, humid kiln air and then to reheat it before supplying it back to the kiln. This diagram shows the pattern of airflow from and back to the kiln including the provision to add auxiliary heat. Auxiliary heat can be supplied from various sources. Equipment configuration including location of heat pump within or outside the kiln can vary considerably.

energy as is consumed by the compressor. Virtually all compressors on dehumidification kilns are driven by electric motors which means that the input energy for the heat pump is electricity. As mentioned previously, the local energy options and costs will play a big role in determining if dehumidification is an economically viable alternative.

With regard to energy efficiency, the entire drying process needs to be considered. Although a heat pump is very efficient, it cannot always meet all of the demands of the drying operation. At some points in the process, the dehumidifying capacity of the system may not be large enough to meet the demands of the material being dried. At those times there is a danger of developing RH levels higher than the intended conditions. If the DH system cannot extract the moisture fast enough from the kiln air, it may be necessary to open over-humidity vents to exhaust humid air and bring in cooler, drier air. At other times, and especially during initial warm-up, the system may not be able to provide all of the heat energy required to achieve the targeted dry-bulb temperature. Therefore, most DH systems are equipped with some sort

of auxiliary heating system. The operation of either the over-humidity vents or the auxiliary heaters will impact on the overall energy efficiency of the kiln.

The above factors need to be taken into account when determining the overall energy efficiency for a DH system. Detailed energy data is difficult to find for any industrial drying system and this includes DH systems. There are various models that have been proposed and applied to predict energy consumption. Information on these is included in Chapter 19. A European study of commercial DH drying systems reported that average energy consumption for softwoods ranged from 0.64 to 0.73 kWh per litre of water removed. These numbers are probably relevant to Canadian softwood species as long as balsam fir is not considered. The higher initial MC and slower drying rate of balsam fir results in greater energy consumption. Fortin (2003) reported that energy consumption for balsam fir is roughly double that for drying black spruce.

Comparative energy consumption data for DH versus heat-and-vent drying is also difficult to obtain, especially for softwood species. Various studies have shown energy consumption to be in the order of 50% of that for a conventional kiln. The relative energy savings may be even greater when considering a drying application where a greater proportion of the total drying cycle involves removing free water. In this situation the com-

pressor will be more heavily loaded for a large proportion of the drying time.

Energy savings do not always translate into cost savings. Fuel costs (both fossil and electrical) are quite variable over time as well as from region to region. Therefore, it is necessary to translate the fuel consumed into an operating cost. If electrical costs are high in your region, it may be advantageous to operate a heat-and-vent kiln even though it would consume more energy. In some regions of the country, electrical energy costs are lower and DH drying can be realistically considered for a wider range of applications.

For maximum energy efficiency and to still achieve a good drying time, it is important to have a good match between the capacity of the DH equipment and the required drying rate of the material. There is a general discussion on sizing of equipment later in this chapter. One of the considerations specific to selecting DH equipment is the size of the compressor chosen. If it is too small, the system will not be able to maintain the desired drying rate. If the compressor is sized to match the peak drying rate (usually near the start of the drying cycle), capital costs will be increased and overall energy efficiency is reduced. When drying higher grades of softwood or hardwood lumber, extending the drying time is sometimes acceptable, however, for softwood dimension lumber, productivity is always a major consideration. Therefore, when selecting or specifying a DH system for SPF drying it is advisable to select a system that will match the maximum (or desired) drying rate.

7.2.1 AUXILIARY HEATING SYSTEMS

Most DH kilns require some sort of auxiliary heating system in order to maintain the desired dry-bulb temperature. Auxiliary heaters are required at start-up to heat the system to a temperature at which the heat pump can operate. This initial temperature is usually specified by the manufacturer and is dependent on the type of refrigerant being used and characteristics of the compressor. Once the kiln has been heated up and the lumber has started to dry, the compressor will provide heat to the kiln air both from the heat pump cycle as well as the electric motors used to circulate air and, in some cases, the motor used to drive the compressor. When the lumber is at a high MC and is drying rapidly, the compressor will run either continuously or for a large percentage of the time. Under these conditions, the auxiliary heaters may not be required. It is also under these conditions that the system will be operating at its peak energy efficiency. Later in the drying process, the drying rate slows and the compressor does not need to operate 100% of

the time. At these times, the auxiliary heater may be needed to maintain the desired dry-bulb temperature.

Auxiliary heat can be provided from a number of sources. Traditionally, manufacturers have installed electrical resistance heaters in the return air duct to boost dry-bulb temperature when needed. The capital cost of adding this is low but operating costs can be high as electrical energy for heat is usually higher than other fuel sources. Other options for auxiliary heat include steam (if a boiler is already present) or hot water. In either of these cases, the energy source can be fossil fuel, electrical or wood residue. Using wood residue provides an opportunity to reduce this portion of the operating costs.

7.2.2 HUMIDIFICATION

The question of the need to inject humidity during the drying of SPF lumber is covered as part of the discussion on drying schedules in Chapter 15. Most DH lumber drying systems (as well as many other drying systems built exclusively for SPF drying) do not come supplied with a humidification system. A complicating factor for most DH operations is that they are not linked to a source of steam which can be tapped into for the purpose of raising the humidity of the kiln air. Therefore, if humidification is required at any point in the process, it is necessary to add some sort of humidity injection system. This could be in the form of a steam generator, low-pressure water spray, high-pressure water atomizing system or some other means. The operating features and advantages/disadvantages of each of these systems are discussed in detail in Chapter 8.

7.3 HYBRID DRYING SYSTEMS

DH drying can be quite energy efficient when the equipment is operating at or close to its capacity. At other points in the process, the system will be less efficient. There are also temperature limits on the operation of the compressor system. It cannot operate below or above a specified temperature range due to limitations with the refrigerant and heat pump. As mentioned previously, auxiliary heat can be used to raise the temperature of the kiln air to a point where the compressor can be started. Some operators and kiln manufacturers have also used these auxiliary heaters to operate the kiln at temperatures beyond what the compressor and refrigerant are rated for. In order to do this the heat pump must be located outside of the kiln chamber and the air flow to it suspended when operating at higher temperatures. Even if the heat pump is shut down, exposing it to temperatures higher than it is rated for will cause damage to the system.

There are several reasons why an operator may want to extend the operating temperature range for their dry kiln. When the wood falls below the fibre saturation point, the removal of bound water is greatly enhanced by operating at higher dry-bulb temperatures. Some woods may also be able to tolerate a higher wet-bulb depression (lower EMC) toward the end of the drying cycle and this may be difficult to attain at the lower operating temperature of the DH system. Inevitably, the main reason for raising the dry-bulb temperature is to accelerate the drying rate. Once the DH system is shut down, vents must be used to remove humidity from the kiln air. At this point, the system is running as a heat-and-vent kiln. By operating the kiln for part of the cycle as a DH kiln and part as a heat-and-vent kiln, the advantages of both systems are realized. This type of drying arrangement is known as a "hybrid" dry kiln. It allows achieving the energy efficiency of a DH system at the early stages of drying combined with the faster, final drying rate of a conventional heat-and-vent kiln. The disadvantages are that the capital cost of having both technologies installed will be higher than either a DH or heat-and-vent kiln and the extra mechanical components will require more maintenance. The heating system installed for a hybrid kiln should have greater operating capacity, both in terms of total BTUs and operating temperature, than an auxiliary heating system typically supplied with a DH kiln. A report prepared by Hydro Quebec showed that a hybrid drying system using a natural gas auxiliary heat system would have a 38% lower total energy cost than a DH system running exclusively on electric power. These savings could help offset higher initial costs.

7.4 VACUUM

Vacuum kilns dry lumber in a sealed chamber with the drying environment maintained below atmospheric pressure. When drying in such conditions, the lower boiling point of water and greater pressure differentials created between the core and surface of the wood result in much faster drying times. Drying times in vacuum kilns vary considerably, depending on the specific technology employed, however, most achieve drying times that are a small fraction (1/4 to 1/20) of the time required in a conventional heat-and-vent kiln. There are also some wood quality advantages from drying wood in an oxygen-free (or oxygen-reduced) environment. Specifically, many of the wood staining mechanisms are partially or fully blocked. Depending on the type of products being produced, this may or may not have an impact on the final product value.

Even though the boiling point is reduced, there is still a need to provide thermal energy to create evaporation of moisture. Most of the water in wood is evaporated and carried away in the form of water vapour. The energy lost from the system in this manner must be replaced in order to maintain the desired wood temperature. The main differentiating feature between vacuum kilns is the manner in which the wood is heated. The following provides a breakdown of the various means by which a vacuum kiln can be heated as well as the potential energy sources and options available.

- Wood Heating Mechanism
 - Partial atmosphere, Superheated Steam Vacuum (SSV)
 - Radio-frequency field used to heat a solid-piled stack (RFV)
 - Cycling between heating at atmospheric pressure and drying under vacuum (discontinuous vacuum)
 - Wood in direct contact with heated platens
- Energy Sources
 - Mostly electric
 - Some offer potential to use other energy sources for heat supply (i.e., fossil fuels, wood residue)
- Options
 - Compressive loading for warp control
 - Steam or water sprays for humidification

By their nature, vacuum drying technologies are more complicated and more expensive to install and operate than the previously described drying options. As with any alternate commercial process, there must be benefits that will at least offset the extra costs in order to make it a viable investment. The two main benefits associated with vacuum drying are faster drying time and preservation of wood colour. Colour is not normally a significant factor affecting value of softwood construction lumber. Therefore, the reduction in drying time is the most significant factor to consider in evaluating vacuum drying technology for an SPF application.

When making economic comparisons of different drying systems, it is important to compare facilities with the same potential annual production capacity. In order to do this it is necessary to have accurate information on the drying times available for the drying technologies being considered. Table 7-1 presents sample drying times for various softwood species, vacuum drying technologies and MC ranges. Production capacity will be the most

significant factor affecting the economic performance of a drying facility for SPF lumber. Therefore, anyone considering a vacuum drying system for this sort of application should seek out existing information or conduct some testing to verify the drying times attainable.

Table 7-1

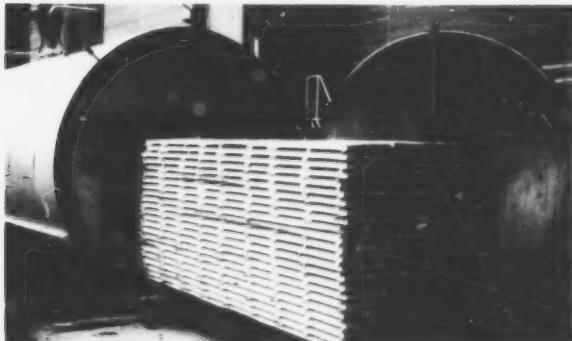
Examples of vacuum drying times for softwood lumber.

Vacuum Technology	Species	Thickness (mm) ¹	MC Reduction		Drying Time (hours)
			Initial	Final	
SSV	Subalpine fir	51	62-82%	15-20%	60
SSV	Western hem-fir	76	70-91%	15-20%	144
RFV	Black spruce	51	25%	15%	4 to 5
RFV	Balsam fir	51	100-110%	10-15%	14
RFV	Balsam fir	51	25%	15%	3 to 4

¹ Based on nominal thickness i.e., 51mm = 2-inch rough green dimension

Figure 7-4

Small-scale superheated-steam vacuum (SSV) kiln. In this kiln type the lumber is piled on stickers and fans are used to circulate the water vapour present in the kiln atmosphere.



7.4.1 SUPERHEATED-STEAM VACUUM DRYING (SSV)

SSV kilns (see Figure 7-4) dry lumber in a partial vacuum but with the presence of pure water vapour (steam with no air present) to provide heat transfer to the wood. The boiling point of water is lower in a vacuum. In SSV drying the dry-bulb temperature is maintained above the boiling point. The steam is circulated at a high flow rate by internally mounted fans. Heating coils are used to reheat the water vapour which, in turn delivers the heat to the lumber. Heat energy can be supplied by steam, hot water or other fluid. As with a heat-and-vent or DH kiln, the lumber must be piled on stickers to provide good contact with the heating medium.

Drying times for this type of system are typically 1/4 or 1/5th what they would be in a heat-and-vent kiln.

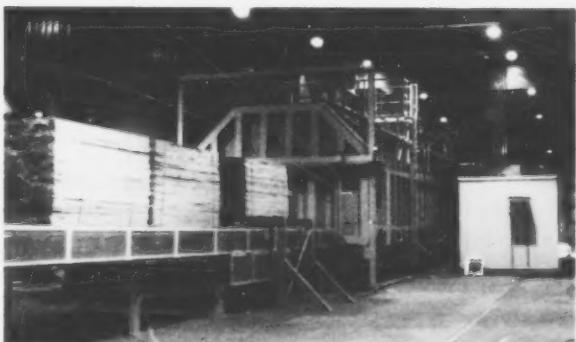
7.4.2 RADIO-FREQUENCY VACUUM DRYING (RFV)

In a RFV kiln a solid stack of lumber is placed between metal plates (electrodes) which are connected to a radio-frequency (RF) generator. The RF field created between the plates, continuously heats the lumber as it dries (see Figure 7-5). A vacuum is maintained and water vapour emanating from the lumber is extracted through the vacuum pump, condensed, and drained from the system. With this system, the lumber can be heated and exposed to a partial vacuum continuously during the drying process. As a result, the drying times for this type of system are considerably shorter than conventional drying systems and shorter than other vacuum drying technologies. Drying times can be as short as 5 to 10% of the drying time in a heat-and-vent kiln.

This technology has been around for many years and has undergone various transitions as the technologies for RF generation and control have advanced. There have been various successful applications of RFV but most of these have been for high-valued products that are difficult or very time consuming to dry in heat-and-vent or DH kilns. The exception with regard to softwood construction lumber has been for the re-drying of "kiln wets". One major North American installation and research conducted by Forintek and Hydro Quebec has shown that this technology can successfully dry "kiln wets". The main advantage for this application is that material can be separated at the planer mill and solid-stacked (rather than re-piled on stickers) for re-drying. The determining factor for a successful commercial application is economic viability. At this point, the higher capital and operating costs do not make this a viable installation for most potential applications. The concept of re-drying is discussed in more detail in Chapter 15.

Figure 7-5

Example of a commercial-scale, radio frequency vacuum (RFV) kiln.

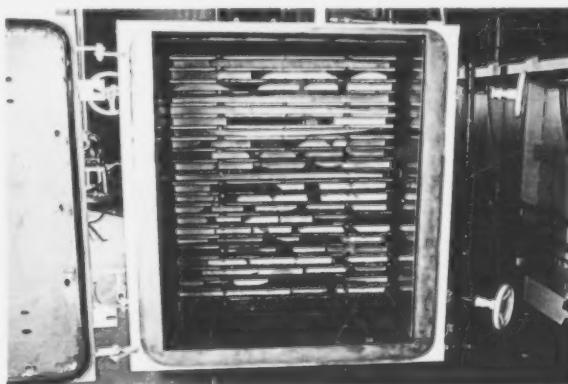


7.4.3 VACUUM/PLATEN DRYING

Another option for heating wood when it is under partial vacuum is by direct contact. Various types of direct contact heating methods have been employed, from electrically-heated blankets to metallic, hollow-core platens that have a heated liquid circulated through them. In either case the lumber stack must be constructed with alternating layers of lumber and heating surface (see Figure 7-6). As with RFV this arrangement allows continuous heating of the lumber while it is under vacuum. Therefore, the drying times are reduced considerably and are usually 1/3 to 1/10 of that achieved in heat-and-vent kilns. A disadvantage, especially for fast drying material is the time and labour required to construct the kiln loads.

Figure 7-6

Lumber in a vacuum kiln can also be heated by direct contact with platens placed between each row, and which (in this example) have a heated liquid circulated within them.



7.4.4 DISCONTINUOUS VACUUM

Another means of heating lumber in a vacuum chamber is to operate, at certain times in the process, with air present. This arrangement requires that the lumber be piled on stickers. When air is introduced to the chamber a heating system, such as a bank of finned tubes, is used to heat the air which in turn will heat the lumber. Once the lumber has reached a pre-determined temperature, the heating system is shut down and the vacuum pump is started. Once the vacuum has been achieved, the residual heat in the lumber acts as the driving force for drying. As the lumber dries, it cools and the drying rate will be reduced. The wood temperature is monitored and when it drops to a pre-determined level air is reintroduced and the above process is repeated. As the wood is not under a continuous vacuum, the drying times will be somewhat longer than other vacuum drying systems. Drying times with this type of system will

be more in the order of 1/2 to 1/3 of that achieved in a heat-and-vent kiln.

7.4.5 ECONOMICS OF VACUUM DRYING

Equipment costs for the various systems described above vary considerably. As mentioned previously, these costs need to be considered in light of the production capacity of the equipment. Despite that, vacuum drying will inevitably be more expensive than most other drying systems to install and operate. Given this, it becomes necessary to assign some monetary value to the advantages of vacuum drying. For example, if solid-stacking material for re-drying is a desirable attribute in favor of RFV drying then the economic impact of that attribute for the operation being considered needs to be determined. In most cases, these are site or company specific evaluations and therefore, no broad statements can be made on the application of vacuum drying for a particular product. Keep in mind the caution made earlier that many of the advantages offered by vacuum drying will only result in economic gain when drying higher-valued products.

7.5 CAPACITY OF DRYING EQUIPMENT

Kiln capacity requirements are discussed in the final chapter of this manual along with other factors affecting the economics of drying. This section will deal strictly with the physical capacity of the equipment and its ability to maintain the intended drying conditions. The drying rate of wood varies considerably from the start to the end of the drying schedule. The initial drying rate is fastest when removing large amounts of free water. This variation is even more pronounced when dealing with species and/or products with an extremely high initial MC or species that are highly permeable.

The peak drying rate will affect the size of the heating system as well as the moisture removal and airflow systems. In many drying situations for other species and products it is not always warranted or justified to design around the peak load but generally something less than the peak to keep capital costs down. In the case of SPF drying, productivity is usually an over-riding consideration and therefore designing around the peak load is often desirable. The peak load will be determined by the nature of the material to be dried and the dry- and wet-bulb temperatures employed (drying schedule) and the amount of airflow. Therefore, it is not possible to give general figures on equipment capacity but is more appropriate to demonstrate the process of determining what the peak loads will be. With this information in hand a mill will be able to check on specifications from potential suppliers and possibly troubleshoot the source

of problems in existing kilns.

In order to demonstrate the process of determining the peak requirement, consider the following example:

Species:	Red spruce
Initial MC:	90%
MC after 24 hrs in kiln:	40%
Specific gravity (density):	0.38 (23.7 lbs/ft ³)
Volume of wood in kiln:	18,000 cu. ft. (approx. 250,000 bd. ft. nominal)
Weight at 90% MC:	810,540 lbs.
Weight at 40% MC:	597,240 lbs.
Water lost:	213,300 lbs. = 21,330 gallons (96,838 litres)
Rate of water loss:	887 gallons/hr (4029 litres/hr)

Regardless of the type of drying system employed, if the wood is to lose the amount of moisture assumed in the above example, the equipment must have the capacity to deliver enough energy to dry (heat and evaporate) that much water from the wood; and a water extraction capacity of at least 887 gallons/hr (4029 litres/hr).

If the kiln cannot meet these requirements then the drying rate will be lower than expected. An important assumption in determining these capacities is the drying rate. Just because it is assumed the wood will lose 50% MC in the first 24 hours and the equipment is sized accordingly does not mean that rate will be achieved. Therefore, it is important to obtain realistic drying rate information based on first hand experience or information gathered from other kilns operating under similar conditions.

HEAT-AND-VENT KILNS

8.1 OVERVIEW

As mentioned in the previous chapter the majority of dry kilns used for drying SPF in Canada fall into the heat-and-vent category. This group of kilns includes what is typically referred to as conventional dry kilns as well as low- and high-temperature variations. There are very few low-temperature kilns employed for the drying of SPF and they will not be covered here, however, some discussion on drying at lower temperatures is included in Chapter 15. Specific descriptions of conventional and high-temperature kilns follow. The term heat-and-vent provides a general, technical description of the manner in which kilns in this category operate. Heat is introduced to the kiln environment to provide energy for drying the wood. As humidity builds up in the kiln environment, vents are used to exhaust a portion of the air and replace it with cool, relatively dry air. The systems of heating and venting are regulated to follow a pre-determined drying schedule. Forced air circulation is achieved by fans normally mounted above the lumber pile. In some cases, a source of humidification may be required in order to raise the relative humidity (RH). All of these components are discussed in the following sections.

8.2 CLASSIFICATION BY OPERATING TEMPERATURE

8.2.1 CONVENTIONAL TEMPERATURE

The term conventional kiln is used extensively in the industry to refer to a wide range of kilns. There is no precise definition on what constitutes a conventional kiln but it is generally applied to kilns in the heat-and-vent category that operate at temperatures up to approximately 200 F (93 C) but which definitely do not exceed the boiling point of water.

8.2.2 HIGH-TEMPERATURE

The term high-temperature kilns generally refers to heat-and-vent kilns that operate with maximum temperatures that exceed the boiling point of water for at least a portion of the drying cycle. In Canada, high-temperature kilns operate with maximum temperatures of up to 230

to 240 F (110 to 115 C). At these temperatures, the mass flow mechanism of moisture movement described in Chapter 6 comes into effect and results in considerably shorter drying times. Drying times will typically be one-half to one-third of what would be achieved in conventional temperature, heat-and-vent kilns. Faster drying does come at a cost. Due to the faster drying rate, the equipment must be designed to both deliver the heat and extract the moisture from the system. In addition, the insulating materials and metal components must be selected to withstand the effects of the higher temperatures. As a result, this equipment will be more expensive when considered on the basis of lumber holding capacity for a kiln but cheaper when considered on the basis of lumber drying capacity.

In addition to the extra costs described above, high-temperature drying does have some negative impact on the material. The process of thermal degradation in wood occurs at all drying temperatures, but is accelerated, and more pronounced, when drying at high-temperature. Some strength properties of wood are decreased as a result of exposure to the higher temperatures. Several studies on Eastern SPF as well as other softwood species have shown similar results. The MOR (modulus of rupture) is reduced in the order of 10 to 12% whereas there is no significant effect on the MOE (modulus of elasticity). A study on full-size Eastern SPF joists confirmed this strength loss but also noted that none of the high-temperature dried lumber fell outside of the design limits for the material. Another consideration with regard to strength loss is that material used for a lot of engineered wood products is now machine stress rated (MSR) after drying. Any effect due to drying conditions will be compensated for by this selection process.

High-temperature drying may also impact the machining properties of the material. The high final dry-bulb temperatures associated with these schedules create extremely low EMC conditions in the kiln. As a result, steeper moisture gradients are created within the cross section of the lumber. Wood at the surface of the boards

may be dried down as low as 3 to 5% MC. The low MC combined with some degradation of the wood fibre will make it more difficult to achieve a smooth finish at the planer. Grain tear out can be an issue. The problem can be alleviated by implementing some sort of equalizing or conditioning treatment. This can be done in the kiln if humidity can be added at the end of the cycle or may be achieved by providing a few days of equalization outside the kiln where exterior EMC conditions will naturally raise the surface MC up to a level better suited for machining.

High-temperature drying is attractive from the stand-point of reductions in drying time, however, the factors affecting product quality should be considered carefully before making a decision on whether or not it is the right choice for a particular application. When comparing the economics also consider whether a conditioning treatment will be necessary at the end of the run. If so, extra time will need to be added to the drying cycle as well as extra equipment costs to provide humidification.

In other areas of the world, high-temperature drying is typically employed on very permeable woods. For reasons of wood structure, wood moisture relations, and physical aspects of drying described in Chapters 2, 3 and 6 not all species will respond well to high-temperature drying. High-temperature drying creates an environment where mass flow will occur and quickly drive out large amounts of free water. The high dry-bulb temperatures are also effective at keeping bound water molecules very active and speeding up the process of bound water diffusion. For mass flow to be effective, the wood needs

to be quite permeable. If not, internal steam pressures can build up and actually create internal explosions and separation of wood fibre. Therefore, species such as subalpine fir, balsam fir, and the "yellow" spruce portion of black spruce will not respond well. The less permeable pieces within these species may develop defects as described above or will at least be the cause of large variations in final MC. The species that have had the best success in high-temperature drying in Canada have been the more permeable portion of spruce such as white and red spruce and jack pine.

Industrial drying times for normal black spruce at high temperature are generally in the range of 20 to 24 hours. Jack pine, which has a low initial MC and is quite permeable, can be dried in less than 18 hours. Guidelines for high-temperature drying schedules are provided in Chapter 15.

8.3 CLASSIFICATION BY HEATING SYSTEM

There are numerous ways in which heat can be delivered into a heat-and-vent kiln. The heating mechanism within the kiln will either be direct-fired or some sort of indirect (radiant) heating system. In a direct-fired system the heat of combustion from the fuel is used directly to heat the air in the kiln. The combustion gases are either mixed with the kiln air or are passed through an air-to-air heat exchange system. The difference with an indirect-heating system is that the heat of combustion is transferred to some other medium which in turn is used to heat the kiln air. This is typically achieved with hot water, steam, or hot oil. Figures 8-1 and 8-2 show cross sections for both direct-fired and indirect-heated kilns.

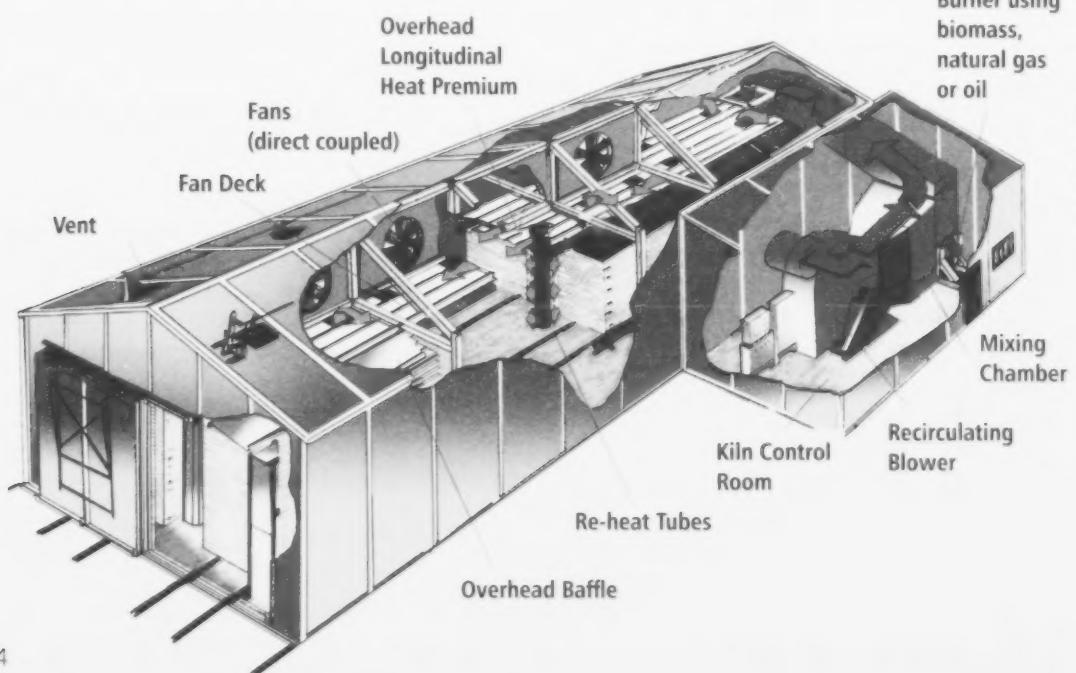


Figure 8-1
Diagram of a double-track, direct-fired kiln, with a cross-shaft fan arrangement.

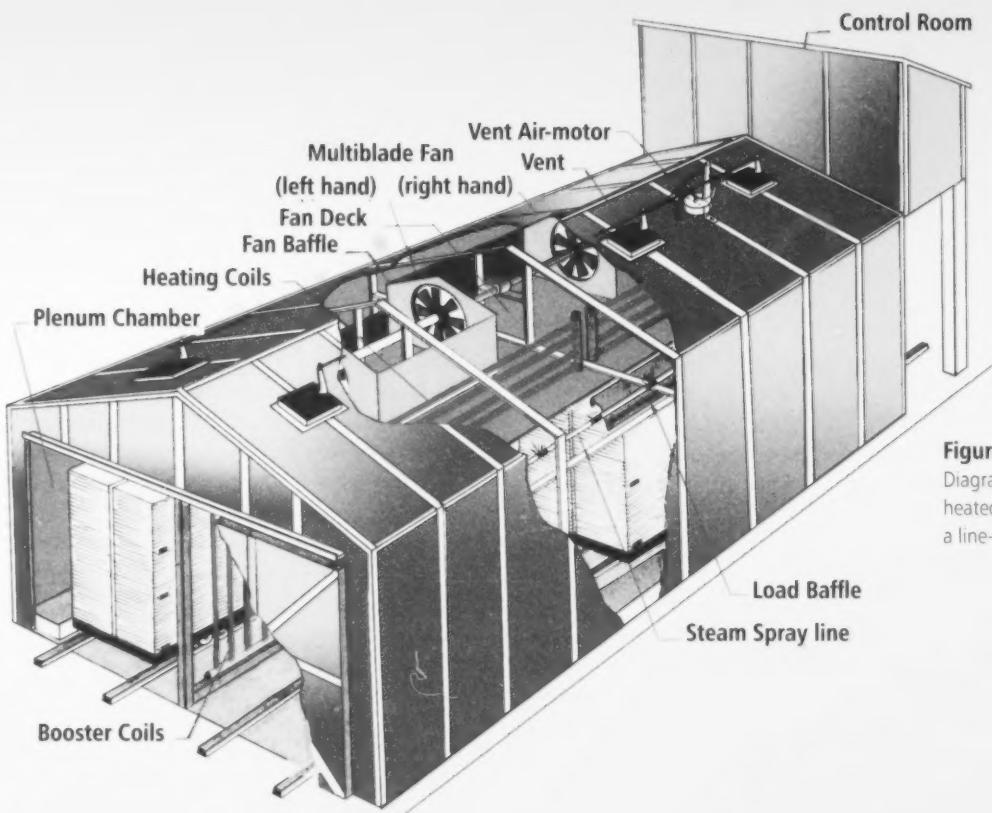


Figure 8-2

Diagram of a double-track, indirect-heated (in this case steam) kiln, with a line-shaft fan arrangement.

8.3.1 DIRECT-FIRED KILNS

This category of kilns is attractive for drying commodity products of SPF for several reasons. Initial cost of the equipment, when considering both the kiln and energy system, will be less than an indirect-heated system. Burner systems for these kilns can realistically be sized to achieve a rapid initial heat-up and maintain a rapid drying rate which may make the drying time somewhat shorter than an indirect-fired kiln. By injecting the combustion gases directly into the kiln, this type of kiln will be the most energy efficient of the various heat-and-vent configurations. Information on energy consumption and comparisons with other drying systems or configurations is presented in Chapter 19.

The rapid heating rates referred to above can be a problem in some situations. When drying a species or product that has a low initial MC, it is common for the dry-bulb temperature to rise faster than the wet-bulb temperature. This can create a wet-bulb depression (and EMC) more severe than intended. This problem can be alleviated by adding some form of humidification system as described later in this chapter. Another concern in operating any

kiln, but in particular a direct-fired kiln is the temperature uniformity achieved in the chamber. Combustion gases from the burner, even after mixing with makeup air, may be over 1,000 F and these gases must be mixed with the kiln air in order to achieve a uniform, but much lower, operating temperature. If the system is not designed or balanced properly large temperature variations can develop in the kiln which can in turn lead to variations in final MC. Temperature uniformity is an issue which should be addressed initially with the supplier and subsequently checked and verified at regular intervals. Most of the burners used on these kilns have only limited capability to throttle back when heating demands are lower. See Chapter 9 for more information on maintaining a dry kiln in good operating order.

Another feature of a direct-fired kiln is that the chamber is more positively pressured than with other heating systems. The huge volume of heated air pushed into the kiln creates higher overall pressures and this contributes to greater leakage, especially around doors, vent openings, and joints between panels. With this type of kiln, more so than others, it is important to maintain a tight structure.

8.3.2 INDIRECT-HEATED KILNS

When a liquid or steam is used as the heating medium, coils can be distributed around the kiln to achieve a uniform heating environment. The heat is generated at a central burner/boiler system which facilitates the use of lower grade fuels such as wet sawdust and bark. There is less of a difference between the temperature of the heating medium and the operating temperature of the kiln which is both an advantage and disadvantage. It is advantageous in the sense that there is less likelihood of developing hot spots within the kiln. The disadvantage is that the lower the operating temperature of the heating medium, the greater the surface area of heat exchanger required in the kiln. This drives the price of the equipment up and any compromises made will usually have the impact of slowing the initial heat up and/or drying rate.

Unlike direct-fired kilns, indirect-heated kilns do not require makeup air to be injected into the kiln and the result is a lower static pressure being developed within the kiln. The impact of this is less leakage around doors and joints in the kiln.

8.4 CLASSIFICATION BY LOADING ARRANGEMENT

Heat-and-vent kilns can be designated by loading arrangement as either a track-loaded configuration or package-loaded. Package-loading kilns are also referred to as "side-loading" or "forklift-loading" kilns. The kilns shown in Figures 8-1 and 8-2 are both examples of track-loading kilns. A typical package-loading kiln is shown in Figure 8-3.

Figure 8-3

Example of a side-loading, heat-and-vent kiln.



8.4.1 TRACK-LOADING KILNS

There are two distinct advantages of track-loading kilns that make them well suited to the drying of commodity grade SPF products. Since charges can be pre-staged, the turnaround time for the kiln can be very short. Most operations can unload and reload a track kiln of 200 MBM or more in 30 minutes or less. Another advantage of this kiln configuration is the relatively short distance that air must travel through the load. The lumber stack on a single track is typically in the range of 8 to 12 feet (2.4 to 3.7 metres) wide. This reduces the variation in temperature and humidity conditions across the load and results in a more uniform drying rate. If the kiln is a double-track configuration, a re-heat system can be installed between the tracks to achieve the same effect across both tracks. A re-heat system may not be necessary on slower-drying products but for most SPF applications utilizing a double-track configuration, a reheat system is essential. Installing a double-track kiln without a re-heat system defeats some of the advantage in selecting this kiln configuration.

The initial cost of track kilns will be more expensive for several reasons. The cost of the track and footings for the track extending to both ends of the kiln must be included in the initial cost. This configuration of kiln requires loading doors at both ends of the kiln which will also increase the price. Additionally, a track-loading kiln will not hold as much lumber per unit area of floor space as a large package-loading kiln. As mentioned above, however, these disadvantages are more than offset when considering a high-production SPF drying operation.

8.4.2 PACKAGE-LOADING KILNS

For the reasons mentioned in the previous section, a package-loading kiln will be more economical on an initial cost basis than a track kiln. Large, package-loading kilns may take 4 to 8 hours to unload and reload making them impractical for a situation where the drying time will only be from 24 to 60 hours long. On this basis, a mill would incur more than 10% down time strictly for the loading operations.

Package-loading kilns do make sense when drying times are much longer or where the dry lumber volume requirements are relatively small. A typical example would be a mill that has a need to dry small volumes of 1-inch spruce or pine for millwork or furniture applications.

8.5 CLASSIFICATION BY FAN ARRANGEMENT

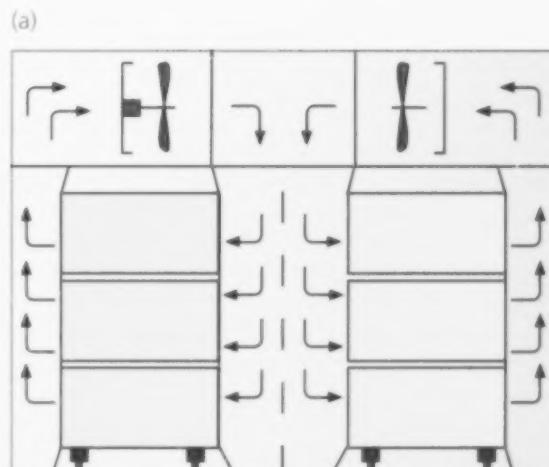
There are two fan orientations that are applied in dry kilns. Figures 8-1 and 8-2 show both the cross-shaft and

line-shaft fan arrangements. When operating at lower rates of airflow the line-shaft arrangement is quite effective. The advantages of this system are that there are only one or two motors to service and these motors are mounted outside the kiln. The cross-shaft fan arrangement is typically employed where higher airflow rates are required. In a cross-shaft arrangement, the fan motors may be mounted either internally or externally depending on temperatures employed, cost considerations and mill preference. Externally mounted motors may be easier to service but the initial cost is greater and there is more maintenance required with the longer shaft length and more bearings.

Airflow requirements are discussed in Chapter 15, however, when airflows of 1000 feet per minute (5.1 metres/second) or higher are required, most suppliers go with a cross-shaft arrangement. Forintek tests on industrial applications have shown that the cross-shaft arrangement can be more energy efficient.

As mentioned in the description of track-loading kilns, it is often desirable to have some form of re-heat system installed on a double-track kiln. The exception to this rule is when the airflow patterns are modified such that the air only passes through a single track on each pass. Figure 8-4 shows how the airflow pattern can be modified to achieve this. The single-air-pass arrangement can be achieved using either a line-shaft or cross-shaft fan orientation. There is a cost saving from not having to install a re-heat system but there may be additional cost incurred depending on the type of fan system.

Figure 8-4
Diagram of a single-pass (a) and double-pass (b) air flow arrangement



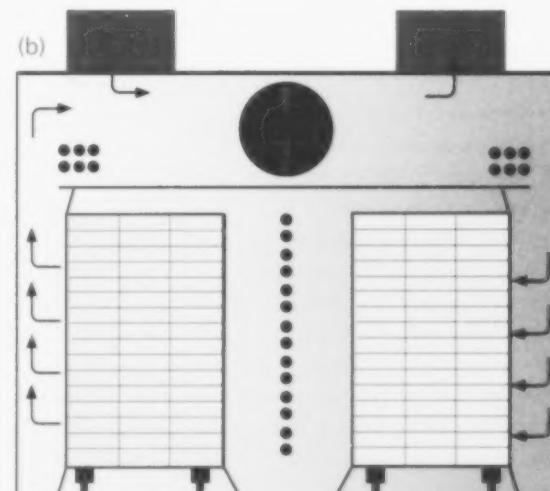
8.6 KILN VENTING SYSTEMS AND HEAT EXCHANGERS

In a heat-and-vent kiln, the vents are the intended way of extracting moisture that is building up in the kiln. As the wood dries, the RH of the air increases and, once it surpasses the set-point, the vents will open to both exhaust hot, humid air and inject cool, relatively dry air. Modern control systems provide options to achieve proportional control of the vents and to adjust the opening of intake versus exhaust vents to account for the difference in air volume requirements in the hot versus cold air streams. This feature helps avoid over-shooting the set-point and helps address the varying demand on venting capability throughout the kiln run.

Since 60 to 70% of the energy consumed in drying is used to evaporate moisture, venting would appear to be an obvious waste of a lot of energy—and it is. As shown in Figure 20-2 heat exchangers have been employed to try to recapture a portion of this energy. These heat exchangers do not interfere with the operation of the kiln. The energy savings and economics of installing heat exchangers are covered in Chapter 20.

8.7 KILN HUMIDIFICATION SYSTEMS

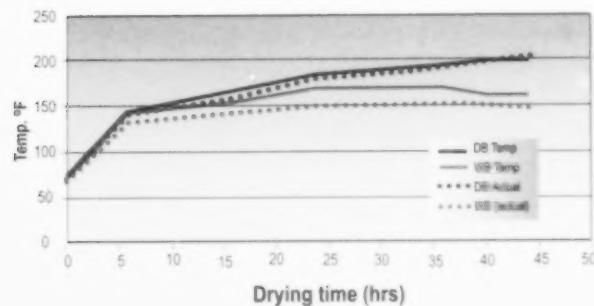
There are a number of reasons why raising the humidity in a dry kiln may be necessary. For some operators it is the need to either equalize or condition lumber. Equalizing is carried out in order to minimize between and within board differences in final MC. Conditioning is done to remove residual stress that has developed as a result of the kiln drying process (see Chapter 15 for more detail on equalizing and conditioning). Both of these post-drying treatments require raising humidity at a time



when there is very little moisture available from the wood. Other situations where extra humidity may be required include the drying of air dried lumber, drying a mixture of species or running a high-humidity schedule to deal with a wet-pocket species. When heat treating lumber for phytosanitary purposes it is also desirable to operate at a high RH. In all of these cases there are a number of equipment additions or modifications that can be made to allow mills to reach the desired RH level.

Figure 8-5

Leaky kilns and/or a lack of a humidification system sometimes make it difficult to achieve the desired kiln conditions as shown in this kiln record. This results in inconsistencies from charge to charge and a more severe drying schedule than intended.



This section provides descriptions of the different options available for raising RH in a dry kiln. As in most situations there is not a single solution that will work for everyone. The solution for a given mill will depend on the specific circumstances such as the type of energy and heating system, condition of the kiln and cost of fuel.

8.7.1 THE CHEAP SOLUTION

The easiest, and usually cheapest, solution to raise humidity in a dry kiln is to rely on the moisture coming out of the wood. For some of the situations described above, such as heat treating and schedule modification, the demand for high humidity may be occurring at a time when the wood still has considerable moisture available. The only way to take advantage of this moisture to raise the wet-bulb temperature is to have the kiln as tight as possible. There are a number of things that can be done to minimize loss of water vapour from the chamber and these are outlined in detail in the following chapter on kiln maintenance.

A well sealed kiln is imperative if relying on using moisture extracted from the wood to raise the humidity level. However, it is equally important when using a supplementary humidification system since the effectiveness

and the amount of energy used by such a system will be affected by how tight the kiln is. A side benefit from sealing up leaks in the kiln is that drying conditions will be more uniform and should help produce a more uniform final MC in the product. The following sections provide some options for supplementary humidification of dry kilns.

Figure 8-6

Leaks in the kiln structure result in a loss of steam that could be used to achieve higher RH (higher wet-bulb temperatures) in the kiln.



8.7.2 LIVE STEAM OPTIONS

Live steam is a very effective way of raising RH. Saturated steam can introduce a large amount of water into the kiln air in a short period of time. If you have an existing steam supply with extra capacity this will probably be your first choice for kiln humidification. The best steam for humidification is low pressure, saturated steam. This ensures a maximum amount of water vapour at a relatively low temperature. The problem with higher pressure steam or steam at less than a saturated condition is that it will push the dry-bulb temperature up faster than the wet-bulb temperature. Pushing live steam into a leaky kiln can also have the same effect. Conditions dangerous to wood quality can develop if the dry-bulb temperature is pushed too high. Furthermore, if the dry-bulb temperature is raised, the depression being sought may never be reached and conditioning of the lumber will not occur. Therefore, when using live steam, ensure that both the kiln and steam supply system are in good condition. High pressure steam can be passed through a de-superheater to both reduce its temperature and pressure.

Some companies have installed steam generators or a small boiler for the sole purpose of producing live steam for conditioning. Steam generators are often electrically heated and, due to the high cost of electricity, are only viable on relatively small kilns. A small-scale boiler can also be used

to produce live steam. This option will have a higher initial cost but operating costs will be lower than an electric system since they are usually fired with a fossil fuel.

Another way of generating live steam in a kiln is by boiling water in place. This technique has been used extensively in New Zealand and other areas of the world to condition and straighten warp prone material. Boiling water in place is usually done by filling a trough along the length of the kiln floor with water and having some sort of submerged heating system. A few mills in Canada have implemented this type of system. This type of humidification system fits well for mills operating with a hot oil or high-pressure steam heating system. In the case of high-pressure steam it avoids both the dry-bulb temperature problem described above as well as having to spray expensive, treated boiler water into the kiln air.

8.7.3 WATER SPRAY SYSTEMS

Water sprays have been used for many years by dehumidification as well as other kiln manufacturers. A pressurized water line and atomizing nozzles are used to inject a fine spray of water into the kiln air. The warm kiln air will quickly evaporate the water, raising the humidity of the air to the desired level. Experience has shown that these systems are most effective when operating at a high water pressure (i.e., 800 to 1000 psi) and using nozzles that produce as fine a mist as possible. The small droplet size with such systems results in quick evaporation of the water. Lower pressure systems produce larger water droplets which either take longer to evaporate or end up hitting the kiln wall or fans and running off as liquid. Low-pressure water sprays may be effective in raising humidity high enough for equalizing but will not be able to achieve the wet-bulb temperatures necessary for conditioning (stress relief). An important consideration in a high-pressure water spray system is the water quality. Depending on the source and quality of the water available, some conditioning and/or filtering will be necessary to prevent clogging of nozzles. Despite that, nozzles for these systems require frequent cleaning and it is often desirable to have an extra set on hand to reduce down time.

8.7.4 OTHER TECHNOLOGIES

Another technology being applied in the Eastern U.S. is known as a spinning disk. A disk with a felt pad is rotated at high speed and water is introduced into the centre of it. As water migrates by centrifugal force to the rim of the disk it is propelled into the kiln air in a fine mist. As with the high-pressure water spray, this mist is absorbed quickly by the kiln air. This system has been applied in a

number of hardwood mills and feedback on the effectiveness of it has been quite positive. Initial tests at a mill in Eastern Canada have also been promising.

8.7.5 IS HUMIDIFICATION NECESSARY?

As softwood producers become involved in more value-added applications for their resource, the question of stress-relief comes up more often. Glue-lam lumber and I-joist flanges are examples of products that may need to be well conditioned to avoid problems during the manufacturing stages or in service. Since many kilns built for softwood dimension lumber do not have humidification systems, companies will need to seek out solutions to retrofit them. The above options should help identify the solution(s) that are most relevant to your particular situation.

8.8 KILN CONTROLS

Kiln controls vary considerably in cost, features and capabilities. Only a brief overview of the range of systems available will be provided here along with some advice on selecting a system.

Kiln controls can be broken into three main categories:

- Manual control systems
 - Manually set temperature and humidity conditions
 - Usually incorporate some sort of recording device such as a circular chart recorder or printer
 - No programming capability
 - No moisture monitoring or automatic shut-down capability
 - Each unit operates a single kiln
- Semi-automatic systems
 - Some means of programming basic schedules such as a time-based schedule
 - Sometimes include a system to record schedules or records of previous charges
 - Can be programmed to automatically shut down based on time
 - No moisture monitoring capability
 - Each unit operates a single kiln
- Fully automatic control
 - Use a computer and/or a PLC to maintain continuous automatic control and recording of kiln conditions
 - Usually some sort of feedback system to assess progress of drying such as:

- DC-resistance pins embedded in boards in the load
- Dielectric probes to estimate MC of individual packages (or partial packages) of lumber
- Use of temperature drop across the load (TDAL) data to estimate intermediate MC levels and/or end point in the drying process
- In-kiln, package weighing system
- By incorporating one of the above, the system is able to tailor the drying schedule to meet the individual requirements of each load
- Ability to program and store a range of drying schedules
- Ability to monitor and control a number of kilns from one computer
- Ability to verify and modify kiln conditions via remote access.

These three categories of control are also distinctly different in price, with the fully automatic systems being the most expensive. Most large-scale SPF drying operations are concerned with maximizing productivity and minimizing operator involvement and are therefore more inclined to go with the more expensive, fully-automated type of system. The best advice in selecting a fully-automated system is to select one that presents the information in a user-friendly manner and that provides as many different options as possible for kiln control. Although a black-box system that removes all need for operator input may seem attractive, such a system may not be able to respond to future needs.

Selecting a system that provides a full range of programming and kiln operating options may take a little longer to become familiar with but will provide more flexibility to deal with new products or drying requirements. As an example, a schedule based on exiting-air temperature may work well for some stud grade products but situations may arise, such as laminated stock, where the ability to run with an entering air temperature schedule will work better. Therefore, a control system able to operate in both of these modes would be desirable. Another desirable feature for an automated control system is the ability to integrate it with other systems. For example, various after-market, in-kiln moisture monitoring devices are now available. To take full advantage of these systems the information needs to be imported to the control system and used as criteria in setting kiln conditions.

MAINTAINING THE KILN

9.1 MAINTENANCE PROGRAMS

Quality drying demands good tools to get the job done. The previous chapters have covered many of the operating features that go toward specifying a good kiln for SPF drying applications. The purpose of this chapter is to provide some guidance on how that equipment should be maintained to keep it doing a good job throughout its serviceable life.

When it comes to dry kilns, by the time something is seen to be broken, it may have already cost a lot of money in lost production or degraded lumber. Feedback time on problems developing in a sawmill is very rapid, if not instantaneous. This is not the case with a dry kiln and problems can go undetected for weeks. This is a consequence of the nature of the equipment and also that personnel are not as intimately involved with it as in a sawmill.

To maintain an efficient drying operation and ensure consistent product quality, it is necessary to have a good preventive maintenance program. In many mills the kilns tend to be the last when it comes to getting time from the maintenance department. This is understandable when considering that most of the working parts of a kiln are in tight working quarters, with warm temperatures, high humidity and often quite dirty. As a kiln operator, the first objective should be to make the job more attractive for whoever has to work there. Keep the kiln clean and cool it down to a reasonable temperature well before any personnel need to enter. This is not only a comfort consideration but also one of safety. Implement a good preventive maintenance program that identifies repairs ahead of time and allows them to be scheduled between charges rather than as an emergency in the middle of a charge.

What constitutes a good maintenance program for a dry kiln? Since kiln types and technologies vary considerably, it is impossible to identify one program that will work for everyone. There are some general points that should be

remembered. First, consider what the objectives of a dry kiln are, and then maintain it to achieve those objectives. The objective is to dry wood in a controlled environment that exposes each piece to, as close as is practically possible, the same drying conditions. There are three aspects of a kilns' operation that impact on this objective: temperature control, relative humidity control and airflow. A good maintenance program will address all of the aspects of the kiln that can potentially affect the control and uniformity of these variables. In addition, there are further measures that will simply prolong the life of the kiln and provide a better return on investment.

The first requirement is to develop a checklist of all the kiln's features that require maintenance. That list can then be sub-divided based on the frequency of attention required in each area. Due to the range of equipment types in industry, it is impossible to list all the possible inspection/maintenance items that need to be addressed. Since drying times are relatively short for SPF (as compared to hardwood schedules), it is important to catch problems quickly. There are items that should be verified daily, whereas other items can be done less frequently. The following tables list some items which should be inspected/verified on a daily (shift), charge-by-charge and monthly basis.

The idea is that all items that can possibly go out of control are identified and entered on the appropriate list so that their operation is verified on a regular basis. Identifying problems with the equipment is the basis of any good maintenance program. The kiln operator(s) and maintenance personnel should be able to identify most of the items for these lists. For new operations, the kiln supplier should be able to help identify the maintenance checklists.

PRE-STARTUP CHECKLIST

Item	Date and Time Checked
<ol style="list-style-type: none"> 1. Start fans and verify proper operation 2. Check and/or replace wet-bulb wick 3. Check water flow to wet-bulb 4. Baffles in good condition and lowered into place 5. Check operation of roof vents 6. Inspect kiln doors and gaskets 7. Set up charge records, list any unusual conditions <p>etc.</p>	

Table 9-1

Sample list of items for a charge-by-charge pre-start-up check list.

DAILY (SHIFT) CHECKLIST

Item	Date and Time Checked
<ol style="list-style-type: none"> 1. Visual check on vent operation (not stuck open or closed) 2. Visual and/or audible check on operation of fans 3. Check oil level on fan bearing oilers 4. Check record on temperatures for any deviations from schedule <p>etc.</p>	

Table 9-2

Examples of items to be checked on a daily basis.

MONTHLY CHECKLIST

Item	Date and Time Checked
<ol style="list-style-type: none"> 1. Check fan rpm on line-shaft kilns to detect belt slippage 2. Check fan bearings and verify tightness of fans on shaft 3. Verify proper operation of fan reversal mechanism 4. Check operation of heat control system 5. Check operation of steam traps (steam systems) 6. Quick check on calibration of instruments <p>etc.</p>	

Table 9-3

Examples of maintenance items to be checked on a monthly basis.

9.2 ASSESSING KILN PERFORMANCE

9.2.1 TEMPERATURE UNIFORMITY

There are other preventive maintenance routines that can be implemented to help identify and correct problems. As previously mentioned, the main objective in operating a dry kiln is to maintain a uniform and accurate drying environment. Dry-bulb (DB) temperature uniformity is one way to measure the effectiveness of a kiln. This can be done by setting up a series of temperature sensors around the kiln. Some controllers offer multiple DB sensors but it is often desirable to set up an independent system so that the operation of the control-

ler can be verified at the same time. A multi-channel temperature data-logger (see Figure 9-1), with a supply of thermocouple wire can be easily set up to monitor the temperature around a kiln. The degree of temperature uniformity required in a kiln is a factor of what is being dried. For SPF drying operations it is suggested that when the kiln is running at a stable condition, all zones of the kiln are within $-\text{+} 5^\circ\text{F}$ ($-\text{+} 2.8^\circ\text{C}$). When checking on the operation of the heating system, it is always best to check the temperature on the air-entering side of the load where the air temperature has not been affected by the moisture condition of the lumber or the rate of airflow through the stack.

Figure 9-1

A multi-channel temperature datalogger (a), such as this 12-channel version, can be used to measure kiln performance with regard to temperature uniformity and accuracy. Thermocouples (b) can be located around the kiln and attached to the load or mounted beside the kiln controller probes.

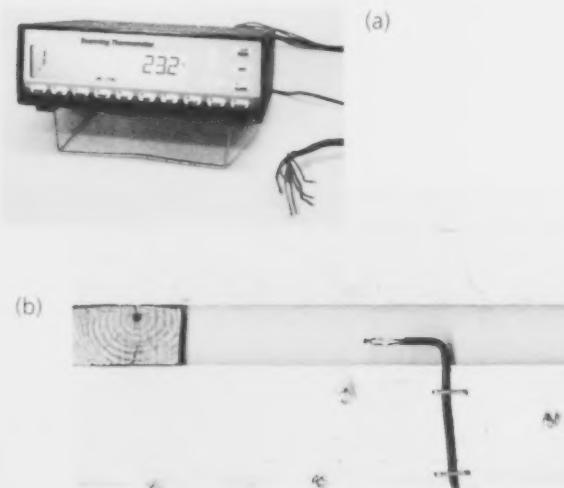


Figure 9-2

Miniature temperature dataloggers such as the one shown here can also be used to monitor temperature in dry kilns, storage areas and shipping containers.

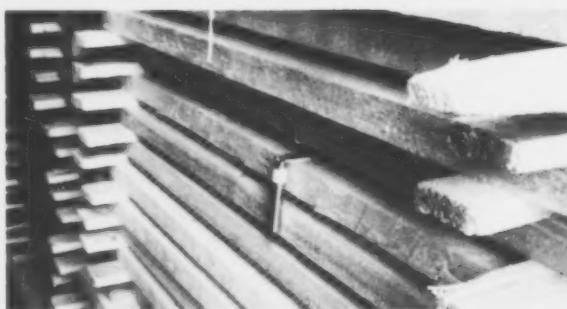
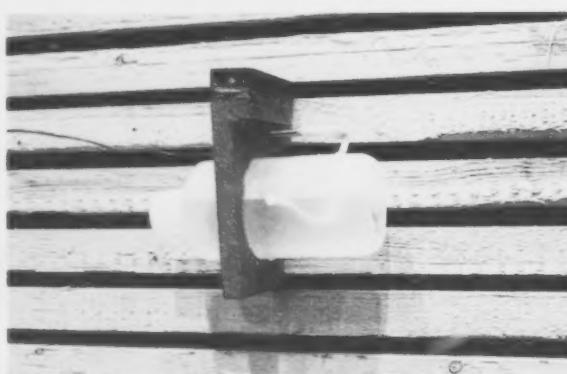


Figure 9-3

A temporary water reservoir and a thermocouple can be set up to test wet-bulb temperature uniformity and accuracy.



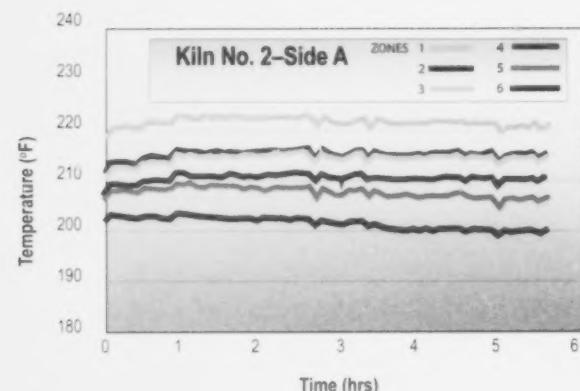
Placing a thermocouple next to the DB sensor(s) in the kiln will provide a means of quickly checking the calibration of these sensors and the control system. As shown in Figure 9-3 a temporary wet-bulb (WB) can also be set up with a thermocouple thermometer to check the operation of the kiln control system. In both cases, the temperature indicated on the control system should be within 2 F (1 C) of the temperature indicated by the independent recording system. Of course, the independent recording system must be properly calibrated for this process to work. A quick (and inexpensive) way to check on this system is to purchase a glass-stem thermometer that is traceable to a calibration standard. Calibration can be verified by placing the glass-stem thermometer and the sensor(s) into a hot-water bath.

The temporary WB sensor shown in Figure 9-3 can also be used to verify the proper operation and calibration of other humidity measuring systems such as EMC wafers and electronic RH sensors.

Figure 9-4 shows a typical result of a temperature inspection on a dry kiln. In this case, thermocouple sensors were set up in a grid pattern on one side of the kiln at 16-foot centres along the kiln and at 4-foot increments in height. This sort of check will help identify either deficiencies in the original kiln design or items related to the heating and airflow system that are not functioning correctly.

Figure 9-4

Temperature data over a kiln run (or portion of a kiln run) can be plotted as shown here to detect areas that are consistently above or below the set point.



9.2.2 AIRFLOW UNIFORMITY

Similar to the process described above for DB temperature, airflow patterns in a kiln should be checked on a

regular basis. The best instrument for doing this is a hot-wire anemometer. The instrument shown in Figure 9-5 comes with a probe that can be extended to facilitate taking readings higher in the lumber stack. Airflow measurements are always taken on the air-exiting side of the load. Again, uniformity is the key to getting good drying. Most SPF kilns operate with an average airflow of 500 feet per minute (fpm) (2.5 metres/second) or higher. At these levels, the recommended degree of uniformity is to have all readings within +/- 100 fpm of the average. When conducting an airflow check make sure that the kiln is fully loaded, the baffles are in place and that the lumber is properly piled and placed in the kiln.

Figure 9-5

A digital reading, hot-wire anemometer such as the one shown here can be used to quickly obtain airflow readings through the lumber stack in a kiln or air-drying yard.



If airflow is not within the suggested range with regard to uniformity, the first thing is to check that all fans are operating and installed correctly. On a line-shaft kiln, the fans alternate between left hand and right hand fans. On a cross-shaft kiln check to ensure that all motors are operating in the same direction at the same time. With twenty or thirty motors in a kiln it is common to find a motor that has been wired incorrectly or is not operating at all.

9.2.3 TEST EQUIPMENT REQUIREMENTS

In order to conduct the tests described above, a kiln operator will need access to a range of test instruments. The following list is a summary of the suggested instruments for a medium- to large-scale SPF drying operation. Considering the value of the kiln equipment, the speed of drying, and the total value of the lumber processed by a kiln, this is a small investment to make.

- Hot-wire anemometer (airflow) or other type of anemometer with a probe small enough to insert into a sticker opening

- Tachometer [check rpm on fan shaft(s)]
- Single-channel thermocouple (or RTD) temperature detector
- Multi-channel thermocouple (or RTD) temperature data-logger
- Glass-stem thermometer calibrated against traceable standard
- Portable wet-bulb sensor
- Infra-red thermometer for spot checks on surface temperature of walls, pipes, steam traps, etc.
- Steam trap tester (if operating a steam boiler).

9.3 MAINTENANCE OF KILN STRUCTURE

Physical abuse and corrosion are the two main enemies of the kiln structure. Physical abuse is usually the result of damage caused by forklifts and mis-handling of kiln doors. The cause of these problems is a management issue but the important thing to keep in mind is if this damage occurs, have it repaired as soon as possible. Holes in the kiln walls provide pathways for water or water vapour to impregnate the insulation and render it ineffective.

Corrosion is an issue for all kilns but certain situations will make it worse for some kilns than others. Running very high humidity schedules will cause more condensation, keeping interior kiln surfaces wet for a longer portion of the schedule and contribute to more and/or accelerated corrosion. The solution is to not necessarily abandon the high humidity schedule but to provide better protection for the structure. Whether considering the concrete or metallic portions of the kiln, the best protection from corrosion is some form of coating. These are best applied when the kiln is new. Coal-tar epoxy can be used to coat concrete and metallic parts. A coatings specialist will be able to identify other coatings that are also effective for these surfaces.

Commercial kiln coatings are typically petroleum-based products that serve a dual role. First they form a physical barrier to prevent corrosion. Secondly, since they are fairly thick, they will help seal cracks in concrete or gaps between panels.

For new kilns, more corrosion resistant components can be specified. In some areas of the world, most of the metallic components inside a kiln are made of stainless steel. This is usually to resist against acidic environments when dealing with wet-pocket species or species like oak and hemlock that have more acidic extractives.

9.4 PRODUCT QUALITY AS AN INDICATOR OF KILN PROBLEMS

As mentioned earlier, the objective of a good maintenance program should be to detect and correct any equipment faults before they result in problems with the product being dried. Ideally this is done by inspecting and monitoring the equipment, however, there is another means of identifying equipment shortcomings. Monitoring the dry product for final MC uniformity and drying defects will also identify problems with kiln equipment. This is where the quality control program should merge with the maintenance program. Setting tolerances for final MC variability and incidence levels of drying defects will help identify when the process is heading out of control. Information on the type and incidence of drying defects can help zero in on a mechanical problem. For example, if there are consistently high MCs and stain at one end of the kiln, look for a fan problem. It sounds simple, but many mills cannot identify from which kiln, let alone which area of a kiln, that a problem package originated.

9.5 REDUCING KILN LEAKAGE

Kiln leakage will contribute to excess energy consumption, non-uniformity of temperature and failure to achieve desired kiln settings. The following steps can be taken to produce a tighter kiln that will help produce a more uniform final MC.

The biggest, and most obvious, source of leakage is around the kiln loading doors. Straightening the doors and re-fitting them with good-quality gaskets will help cut down leakage. Door gaskets should be considered as a regular maintenance item and expect to change them every year or two or sooner if damaged. Using some sort of clamping or hold down device to push the doors tighter against the kiln wall will also help reduce leakage. A particularly poor area for contact is along the bottom of the kiln doors. Again, using a good quality rubber gasket will help. The floor or sill plate below the kiln door must be kept in good shape to provide a good surface for contact. On track kilns there is the problem of sealing around the tracks. Some operators will block these areas from inside the kiln with a bag of sawdust, or something similar. Some kiln manufacturers provide a removable section of track below the kiln door that avoids the problem of having to seal around the rails.

Other sources of leakage around the kiln are the joints between panels and the contact between wall panels and kiln footings. Again, good kiln maintenance will help minimize the problem. Large gaps can be filled with epoxy-based filler or a closed-cell expanding foam

insulating product. Seams between panels and small gaps can be sealed with a good quality silicone sealant. Good surface preparation is required to ensure proper adhesion of the silicone. Also, some of the commercial kiln coatings are thick enough that they will block minor gaps between kiln components. Regular application of an internal kiln coating will also help extend kiln life by reducing corrosion problems.

The kiln vents are another area where needless loss of humidity occurs. Obviously the role of the vents is to get rid of humidity but this should only be when they are open. When closed, the vents should be adjusted to fit as tightly as possible. If a kiln has too many vents, consider closing some off permanently to reduce losses. A centralized venting system, such as that used with some heat exchanger systems, will also help minimize unwanted losses. A cold day in the winter is a good time to check how well things are sealed in this as well as other areas of the kiln.

Another consideration with the existing equipment is the amount and condition of insulation. Condensation on interior surfaces of the kiln walls robs some of the moisture from the kiln air. Cutting a few inspection holes in kiln walls and doors will reveal if the current insulation is in good shape (see Figure 20-1). Thicker, better insulated kiln walls not only reduce the potential for condensation but are inherently better sealed to reduce the type of leakage losses described above.

Direct-fired kilns are more positively pressurized than kilns with other heating systems due to the addition of make-up air at the burner. As a result, leakage from these kilns will be greater, especially if they are in poor physical condition. Using a variable speed drive for the make-up air fan will help reduce the amount of pressurization at times when the burner is not on high fire. When trying to raise humidity in a direct-fired kiln, a well-sealed structure is doubly important.

9.6 MAXIMIZING FAN EFFICIENCY

Regardless of age, many kilns do not operate at their peak capacity or efficiency when it comes to the air flow system. A quick check with an anemometer (air flow meter) and call to the kiln supplier will reveal whether or not the kiln is operating at its design capacity. Regardless of the outcome of that test, there may be ways to get more from the existing fan and motor combination. Many kilns are equipped with variable pitch fans and/or variable speed drives. Both of these can be regulated to achieve the maximum output. Most drying operations

can benefit from increased air flow by reducing drying time and/or improving on final MC uniformity.

Hot air is less dense than cooler air and is therefore easier to circulate. The result is that fans that may be highly loaded at start-up will have extra capacity when the air is heated. If a variable speed drive is used, this phenomenon can be used to advantage. By starting the fans at a lower speed the maximum load on the motor can then be achieved once the kiln air is heated. This will result in a faster air flow when the kiln is at operating temperature, and may reduce drying time.

Operating parameters on fans can be verified and/or modified to achieve the maximum output. A tachometer will quickly reveal if the fan and motor combination are turning at the correct rpm. A quick check with the fan and kiln manufacturer will help determine the design value for a given operation. It is not uncommon to find motors or pulleys that have been changed since the kiln was first installed that have reduced the output of the fan system.

Variable pitch fans can be adjusted to achieve the maximum airflow for a particular situation. The fan manufacturer can provide information not only on the design speed (rpm) but also the range of fan blade pitch that can be tolerated. The objective is to achieve the maximum out of the fan/motor combination. If the fan motor is not drawing something close to its maximum current there is an opportunity to adjust the fan pitch to increase airflow. The pitch can be increased until the motors have reached something close to their capacity. If there is a variable speed drive, it can be used in conjunction with the fan pitch adjustment to optimize performance in a heated kiln as described earlier in this section.

STORAGE AND HANDLING OF LOGS/TREE-LENGTHS PRIOR TO DRYING

10.1 OVERVIEW

There are a number of factors arising from the manner in which green lumber, logs or tree-lengths are handled prior to reaching the kiln that can potentially affect how the lumber responds in the kiln. A good kiln operator will make themselves aware of the full history of the material in order to make the best decisions at the kiln. The purpose of this chapter is to consider what happens to the material during the stages prior to drying and how that may affect decisions made at the kilns.

10.2 STANDING DEAD TIMBER

Insect infestations and forest fires are two possible explanations why material may exist in the forest in the "standing dead" state. There is increasing pressure on industry to utilize this fibre source rather than to let it go to waste. If harvested and processed within a reasonable amount of time this material can produce a good quality product. The precise definition of "reasonable time" varies considerably depending on the reason the trees died in the first place and the local conditions that the material is exposed to after dying. In most cases, it seems that this material must be processed within a maximum period of 2 to 3 years after mortality. Beyond this time period, wood rotting fungi become more established and deteriorate the wood fibre extensively. Within this time period, however, there are changes to the wood that will affect how it is handled at the kiln.

In the standing, live tree (as well as fresh, green logs), the bark acts as a natural barrier to inhibit drying. Once the tree dies, the inner bark starts to dry out, crack, and, over time, begins to fall off. This allows the wood underneath to also start drying. Before that happens, however, the wood is likely to stay at an elevated MC (over the fibre saturation point) for a sufficient period of time to allow the development of blue-stain fungi. These fungi do not have a significant effect on either the strength or drying properties of the wood but they do affect its marketability. Longer term exposure of the wood at elevated MCs will result in the development of

wood-rotting fungi which do have a significant effect on strength properties. Wood with incipient decay will also dry out much more readily. The objective, therefore, is to get the timber to the mill and processed before any significant amount of wood-rotting fungi have become established.

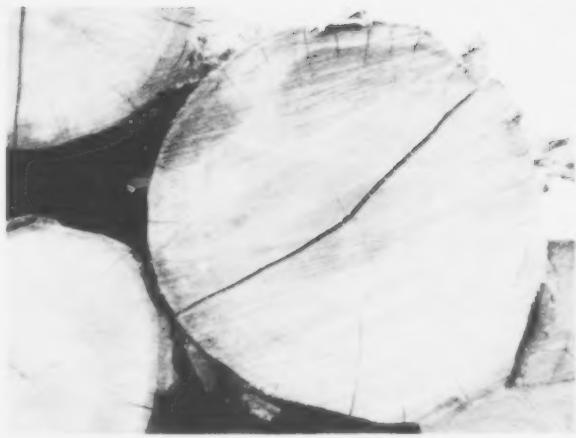
Standing dead timber will begin to dry shortly after the trees have died. Damage to the outer portion of the stem, whether from insects or fire, will expose the wood and allow it to begin drying. Since not all trees are affected equally, certain trees will dry out readily while others (perhaps still alive) may remain in a close to green condition. Therefore, one of the challenges posed by processing this type of timber is the variability in MC that will likely be present. Much of the material may already be at or below the required final MC while other material is still well above that level. One way to deal with this variability at the mill is to install a pre-sorting system that will differentiate between low and high MC material.

10.3 LOG STORAGE PRACTICES

Another stage of timber processing that can have a significant effect on the moisture condition of the lumber delivered to the kilns is log storage. Timber harvesting and inventory practices vary considerably across the country in the SPF industry. Again, it is usually a case that the kiln operations must be adjusted to suit the needs of the material delivered to them rather than changing the logging or inventory practices. Material held in inventory for long periods of time will dry out from the log ends as well as through the bark. What is different from standing dead timber is that log piles will only dry out from the exposed surfaces. Therefore, as shown in Figure 10-1, the upper rows of logs or tree lengths and the log ends will be the material that dries out significantly during the storage period. Inner portions of the log pile will take considerably longer to dry out. It is not uncommon to open up log piles in July and still find ice and snow. The issue created for the dry kilns is one of variability in MC.

Figure 10-1

Log ends as well as exposed logs in a lumber pile will dry out preferentially causing the development of end and surface checks and contributing to variations in initial MC.



There are ways to deal with most situations posed by variability in initial MC. Some of these procedures may impact on either productivity or grade recovery after drying. By involving the kiln operator from the outset, the possible implications of processing certain mixes of material can be identified and decisions made accordingly.

There are some things which can be done at this stage to minimize the impact at the dry kilns. Good inventory management to ensure a supply of even-aged logs to the sawmill will result in a more uniform initial MC distribution. Aside from maintaining a large inventory of logs or tree-lengths, many mills will continue to receive a certain portion of fresh, green material over the year. From a drying standpoint, it would be better for the fresh, green material to be processed in batches so that it could be identified and treated differently when reaching the kiln. Similarly, if the kiln operator receives kiln loads composed of older, but uniformly aged material, better decisions can be made on how to deal with it at the kilns. Schedule modifications for dealing with particular situations such as low initial MC or variable initial MC are discussed in the section on drying schedules in Chapter 15.

10.4 AWARENESS

It is usually the case that the drying operations must adjust to the realities of the situations posed by less-than-ideal storage and handling practices. In order to do this, the kiln operator must be aware of the condition of the material delivered to the kilns. The best way to achieve this is to maintain lines of communication among all the various stages of manufacturing. This will help avoid any surprises either when the material arrives at the kilns or, more importantly, when it leaves the kilns. The kiln operator and kiln operations should be involved in, or at least informed of decisions on how to store, handle and process tree-lengths and logs.

PRE-SORTING AND ITS IMPACT ON DRYING

11.1 INTRODUCTION

A certain portion of Canadian lumber producers involved in the manufacture of SPF dimension lumber have been sorting lumber prior to drying since the mid-1980s. Gradually, companies have moved from the situation of drying all SPF in a mixture, to sorting by species and more recently (mid-1990s) to sorting by species and/or other characteristics such as initial MC and green density. Pre-sorting green lumber offers the potential to reduce drying time, reduce energy consumption, improve grade recovery, improve final MC uniformity, and minimize excessive shrinkage.

This chapter provides some background on green lumber characteristics that have an impact on drying rate and can therefore affect drying uniformity within the SPF grouping. It also presents information on current technologies being used in Canadian sawmills to pre-sort green lumber to improve overall drying efficiency. The challenge for mills is to find a pre-sorting technology that best addresses their particular raw material situation, can be easily implemented, and will deliver a tangible return on investment for the specific sawmill environment.

11.2 BACKGROUND

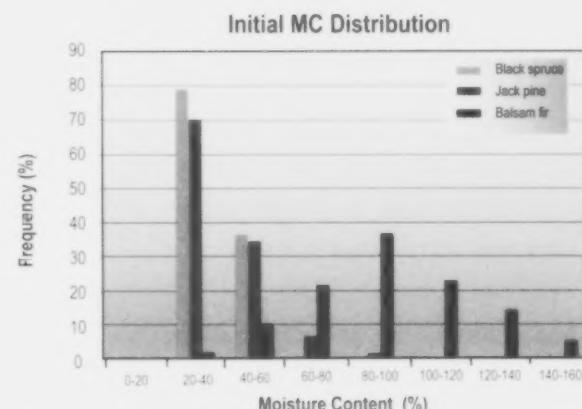
Large variations in initial MC and drying rate within or between species in the SPF grouping results in a wide range of MC after drying. Since SPF lumber is processed in large batch kilns, it is necessary to over-dry most of the boards in a kiln load in order to ensure that the percentage of wet boards meets the grading authority or customer requirements. Over-drying causes increased shrinkage and warp, which in turn, increases the percentage of down-graded boards and thus decreases product value.

Reducing the input variability of a batch process like SPF drying will also improve overall productivity. Slower drying material will be dried separately, thus reducing the kiln residence time for faster drying material. Even if the slower drying material is dried on a longer than normal

schedule, the volume of material dried on this longer schedule is usually small and, as a result, the average drying time is still reduced.

Figure 11-1

Inherent variations in initial MC both between and within species are reasons why sorting on the basis of this parameter can result in more uniform (from a dryability standpoint) kiln charges.



The effect of wood properties on drying rate is covered in Chapter 2. In general, the following species-specific wood characteristics have an impact on drying time and uniformity:

- initial MC and its variability
- basic density and its variability
- sapwood vs heartwood proportion
- growth rate
- wood permeability.

In order to optimize drying performance, mill staff need to find ways to supply their dry kilns with homogeneous lumber without incurring excessive sorting and handling costs. Various Forintek studies have demonstrated that initial MC is not the only physical criterion for pre-sorting lumber prior to drying. Bulk (green) density, which is the weight of a piece of green lumber divided by its actual volume, is a good indicator of its drying time. This is

explained by the fact that green density is a function of the amount of water present for a given volume (which is the moisture concentration) and the weight of wood fibre for the same volume (which is the basic density). Both of these factors affect either drying rate or drying time, or both.

The first generation of pre-sorting equipment was designed to measure and estimate the MC of green material. The belief at that time was that drying time was directly related to initial MC. More recent advances in sorting equipment have addressed the concept of "dryability" to justify their performance. "Dryability" can be defined as the drying behaviour of each piece of lumber either at a given time or throughout the drying process. The idea behind dryability is to identify and isolate pieces that will dry in a similar time regardless of how they may differ or resemble each other with respect to any single property. As an example, a piece of sapwood lumber may dry in the same time as a piece of heartwood, at a lower initial MC, since the sapwood is generally more permeable and will release its moisture more readily. These two pieces could be said to have the same dryability.

11.3 INDUSTRIAL PRE-SORTING PROCESS

11.3.1 NON-AUTOMATED SYSTEMS

11.3.1.1 VISUAL SPECIES SORTING

Most of the time species sorting is done at one of three processing steps; during the harvesting operations, at the log handling stage just prior to entering the mill or just before the sawmill's lumber sorting system. The choice of which of these to use is driven by various processing considerations. This could include, but would not be limited to, the proportion of species in chips going to a pulp or paper mill or the mix of log sizes fed into the sawmill. Since different species often have different tree size characteristics feeding one species at a time into the sawmill may not be desirable. Many mills have been set up to run efficiently when handling an expected range of log sizes.

Species sorting in the bush incurs extra costs such as more handling by the harvester to produce and manage separate piles, extra distance to carry tree-lengths or logs and dealing with a larger number of piles for trucks loading in the bush. Once the material arrives at the sawmill extra costs arise from more complicated yard management. Some conditions can make species identification less reliable such as night harvesting operations or completely unreliable such as harvesting a fire-killed stand. Depending on who is doing the harvesting, the

extra costs of sorting in the bush are either incurred directly or are passed on by the logging contractor. This option must therefore be compared against other sorting scenarios based on the impact of total cost and effectiveness.

Some mills have implemented sorting at the infeed to the sawmill by identifying bark characteristics of the logs. It is generally the fir species that are of interest for sorting and, in many regions of the country, it is easy to distinguish fir logs from either spruce or pine. When occurring in a relatively small proportion the fir logs can be set aside for processing at a later time.

Species sorting at the mill is done visually by operators on sawn lumber. They will look for various visual indicators such as colour, knots and appearance of wet pockets to identify fir lumber. They often use fluorescent crayon to place an identifying mark on the lower proportion species (usually the fir pieces) at the trimmer station and prior to the bin-sorter. The identification must be done at production rates that are often in excess of 2 pieces per second. Non-uniformity in sorting performance is often the result of these high production speeds.

To implement pre-sorting, sawmills require extra bins to handle material for each lumber dimension that is sorted. The cost of extra bins is often the limiting factor when implementing any pre-sorting scenario at the sawmill. Visually sorting by species may offer more flexibility than automated systems with regard to sorting capacity requirements. Some mills that are visually sorting by species have set up sorting rules to deal with a specific part of their lumber supply in order to reduce over- or under-drying. As an example, heavy fir containing wet pockets (often called "blue fir") can be set aside for air drying before kiln drying.

11.3.2 THE AUTOMATED SYSTEMS

Canada has pioneered in the area of sorting equipment and still leads in the development of new technology. There are a number of technologies, some already well established and others just emerging, that offer the potential to sort lumber prior to drying. The challenge is to find a technology that will work well in a sawmill environment, is capable of sorting lumber into groups with similar drying characteristics and is not too costly.

Automated sorting systems can be divided in two main groups, those making spot or point readings at one or more places along the board's length and those that scan the entire piece. Most of the existing technology belongs within the first group. These systems provide

the advantage of being able to provide information on within-board variability of the measured property. As an example, these systems can potentially provide information on the occurrence and severity of wet pockets within the different sorted groups of material. That information can then be used to develop new drying strategies such as electing to air dry a specific "problem" group of material. The inherent within-board variability of each species should be considered in determining the best number and location of sensors. A system designed for sorting fir lumber would ideally have more sensing points than a system designed for pine or spruce.

The second group of pre-sorting systems is comprised of those that take a single reading for the entire piece such as a weight-based sorting system that weighs the full board. These systems have the advantage of being able to provide information on the entire board and are less influenced by local characteristics of the wood such as wane, knots or decay and variations in the proportion of sapwood to heartwood.

11.3.2.1 MC-BASED SORTING

The first industrially implemented initial MC sorting system was developed by Forintek in the mid-1980s and was based on the principles of heat capacity and thermal conductivity. The operating principle was based on the known heating properties of wood and water and using infra-red thermometry to scan surface temperature. When the surface of a piece of wood is heated, its temperature rises, but the amount of temperature increase is affected by the wood's MC. If the wood is relatively dry, it heats up quickly. If the same heat source is applied to wood with a relatively high MC it will not achieve the same temperature increase. By applying an equal amount of heat to each piece of lumber on the production line and then measuring its temperature before and after, the change in temperature can be used to estimate the lumber's MC. There were problems correlating the change in temperature against MC, mostly due to limitations in surface temperature measurement and the need to correlate spot estimates of MC to the MC of the entire board.

The next system designed to measure initial MC was based on the primary response characteristics of a material exposed to a laser beam. Similar to the infra-red technology described above it took spot readings, correlated those to MC and then allowed the user to set the sorting criteria. This technology was relatively expensive and, as a result, did not gain a lot of application and acceptance in the industry.

Another commercial pre-sorting technology has been developed based on the use of infra-red imaging. It uses sophisticated spectral imaging technology and instead of focusing on specific points along the length of the lumber, the system analyses the entire piece of lumber. The surface of each board is mapped and a graphical representation of the water distribution is available to the user. The principle of the system is that the wood temperature will decrease due to evaporation of moisture and the evaporation rate will vary across the surface and from board to board based on the wood MC and drying properties. Thus for the same ambient conditions, a wetter piece of wood will be cooler than a drier one. These systems are calibrated in units of MC but in reality the calibration is a relative one. Wetter, faster drying pieces of wood will have a lower temperature than dryer, slower drying boards. The manufacturer prefers to convey the idea that its system sorts lumber based on its ability to release moisture, that is, on its potential ability to dry.

11.3.2.2 WEIGHT-BASED SORTING

Several equipment manufacturers have introduced equipment using load cells to obtain dynamic measurements of individual board weight at the green chain at normal mill operating speeds (see Figure 11-2).

Figure 11-2

A commercial sorting system based on green weight utilizes load cells along the green chain to measure individual board weight.



If the exact dimension of each board is known, from a sawmill scanning system for example, it is possible to calculate the bulk density. If exact dimensions are not known nominal dimensions can be used to determine an estimated volume. In these cases, however, the green density of wany boards will be under-estimated.

Also, when nominal dimensions are used, boards that are thicker due to sawing variation will appear to have a higher green density and may get placed in a slower drying group, which is not a mistake since thicker lumber will take longer to dry.

These systems are being used mainly in Eastern Canada (Quebec, New Brunswick and Nova Scotia). They have demonstrated a good capability to sort balsam fir into two or three distinctive groups and have been also used to segregate the dense black spruce called "yellow spruce" (see Chapter 1) from normal black spruce.

11.3.2.3 DIELECTRIC SORTING

Dry MC detectors based on measurements of dielectric properties were used in the 1980s by some mills to pre-sort green lumber. These systems were used in some cases to sort fir from spruce with relative success under summer conditions. The principle did not work well on frozen lumber, which is a significant weakness given the Canadian climate, and as a result did not gain widespread application.

In the mid-1990s another system based on dielectric properties was introduced to the Canadian market. The system measures certain dielectric properties of wood which are influenced by MC and density. Since the meter does not distinguish between these two properties, the resulting reading is the combined effect of both. The output from the system is a number between 0 and 100 which relates to potential dryability. Sensors are typically installed in pairs with one located above and the other under the lumber as it is conveyed on a transverse chain (see Figure 11-3).

Figure 11-3

This in-line, green lumber sorting system measures a dielectric property of wood with sensors mounted both above and below the lumber and at multiple points along the length.



This arrangement allows measurements to be taken on both wide faces of the lumber. Depending on the length of the lumber, four or more pairs of sensors are located across the width of the deck to obtain readings along the length of the lumber. There are over 100 systems of this sort currently installed with most of these located in Western Canada.

11.3.2.4 pH-BASED SORTING

In the late 1990s, Forintek developed a system to automatically sort balsam fir being processed in mixture with other species of the SPF grouping. The system uses an alcohol based pH indicator which when sprayed onto the end of a board reacts with naturally occurring wood chemicals to produce a colour change. A fibre optic detector analyses the colour change and then assigns boards into specific sorts based on pre-determined sorting criteria. The system segregates all high MC balsam fir from spruce based on the colour change. Low MC balsam fir pieces do not produce the same colour change and are placed in the same group as spruce. High MC spruce sapwood boards do not react the same as lower MC spruce and are grouped with balsam fir. Considering the drying characteristics of the material this is the ideal sorting placement for this material. As a result the system is marketed more as a dryability sorter. Results of a mill study in the Maritime region of Eastern Canada have shown an increase in kiln productivity of 19% and a decrease in over-drying. This system is being used in SPF mills in Nova Scotia, New Brunswick, Quebec, Ontario and New Hampshire.

Figure 11-4

A commercial pre-sorting system uses a chemical indicator that is sprayed on board ends and changes colour based on species and other characteristics of green lumber. An optical system is then used to assess the colour change and sort lumber into different groups for drying.



11.3.2.5 GAMMA RAY SORTING

A New Zealand company has developed a non-contact system, based on gamma ray technology for sorting green lumber by density and, if required, by MC. This system uses very low-energy gamma rays emitted by a source placed beneath the lumber chain. Gamma ray count is measured continuously by a detector placed above the lumber chain. When a piece of lumber passes between the source and detector, some of the gamma particles are absorbed by the lumber, so the count rate at the detector goes down. The amount of decrease is proportional to the green density of the lumber and the thickness of the lumber. There are very few systems in place at this time and therefore very little information available on the effectiveness of this technology.

11.3.2.6 DC-RESISTANCE SORTING

More recently, another sorting system based on a DC-resistance technology has appeared on the market. The system combines two different steps of measurement. A first station called the pre-sorter is located at the sawmill green chain. It uses DC-resistance measurements combined with weight to assess the lumber's dryability. The system has shown good performance with mixed fir and spruce operations. By assessing the dryability of each individual piece, the system distinguishes fast-drying pieces of fir that can be dried on a fast spruce schedule and slow-drying spruce that can be dried with fir. The system can sort the production into two or three distinct dryability groups. A second station located at the planer mill measures the final MC and feeds the information back to the pre-sorter to optimize the sorting strategy. The in-line system at the planer mill uses DC-resistance measurements taken at four locations to estimate the final MC of lumber. The DC-resistance measurements taken at the sawmill and planer mill are compensated for wood temperature when developing estimates of the wood dryability or MC.

11.4 FEASIBILITY AND BENEFITS OF PRE-SORTING

Research has shown that significant drying benefits are attainable through pre-sorting. Pre-sorting green lumber has the potential to reduce the average drying time, the incidence of wets and/or over-dried pieces and drying degrade. One Forintek study at a Northern Ontario mill reported specific drying benefits from pre-sorting jack pine into two different initial MC categories. Kiln productivity was increased by 9%, energy consumption was reduced by 8.7% and the proportion of material down-graded was decreased by 7.9%.

Species sorting is the first strategy to consider when investigating pre-sorting options for a mill processing balsam or subalpine fir in combination with spruce or pine. A Forintek study reported up to a 30% increase in kiln productivity and 57% reduction in over-dried boards resulting from the implementation of species sorting at a mill with a 57:43 ratio of spruce to balsam fir. Mills processing just pine and spruce will also benefit from species sorting but the gains are less since the two species have more similar drying characteristics. Even minor differences in drying time between spruce and pine can offer an opportunity to optimize the drying operations and produce a more consistent and higher quality product. Another potential advantage in sorting pine from spruce is that pine is a more permeable wood and can withstand higher drying temperatures. Also the pine species are less prone to downgrade during drying since they exhibit less of the characteristics associated with warp such as compression wood and severe slope of grain.

Linking species sorting with other criteria such as MC or green density is the next step to consider in optimizing benefits from pre-sorting. By gathering more information on factors that are known to have an impact on drying, smarter decisions can be made on how to pre-sort the material. Doubling up on the number of scanning systems does not necessarily result in the need for more sorting capacity over and above what was required when sorting based on one parameter. Consider the situation for a hypothetical mill laid out in Figure 11-5. In this case information on both species and board weight are considered when deciding how to recombine the material into groups with similar drying requirements.

When it comes to material sorting strategies there is no one solution that is good for all mills. The species proportions, log handling and storage practices, and drying demands are sufficiently different from mill to mill that a site-specific evaluation must be conducted to identify the best technical and economic solution. Increased awareness of material drying properties and competent in-house technical capabilities will allow mills to conduct a review of their material sorting options that will best suit their needs.

When it comes time to identify, justify or implement pre-sorting strategies, mill personnel need to consider a lot of information. Forintek has developed a methodology and software tool, called OASIS™, to help identify the best sorting strategy for a specific fibre supply and taking into account mill-specific constraints. OASIS™ helps mills simulate a wide range of pre-sorting scenarios and provides a drying simulation component. This decision-

Figure 11-5

Example of how two different pre-sorting technologies can be combined to make better matched groups of material for drying without necessarily doubling the number of groups.

Spruce & Pine

Fir

Weight based Sorting

Very heavy Spruce

Moderate to heavy fir

Weight based Sorting

Regular spruce & pine

Drying Group 2
Heavy spruce and moderate to heavy fir dried on a long, gentle schedule

Light Fir

Drying Group 3
Very heavy fir sent to air drying yard for pre-drying

Drying Group 1

Regular spruce & pine
+ light fir dried on an aggressive schedule

assist tool has been developed to help identify the optimum sawmill pre-sorting strategy(ies) based on impact on drying degrade and kiln productivity. With OASIS™ the user can simulate various pre-sorting scenarios including species, initial MC, and green density or a combination of these criteria. Benefits are evaluated based on kiln productivity and proportion of pieces over- or under-dried. The user can set the species proportion at his sawmill or simulate future trends of the species mix.

Figure 11-6 provides a sample of the input requirements and output generated by OASIS™. By re-running the software multiple times with different sorting scenarios, a user can zero in on the best solution for their mill. The output results can be used to determine the net economic impact to the mill of implementing pre-sorting. From there the mill can compare the benefits against the cost of installing the pre-sorting technology and extra sorting capacity required and determine a payback for the investment.

OASIS™ has several general databases available for mills to use, however, the best results are obtained when a site-specific database is developed. This entails taking a small, representative sample of material and drying it

in a small kiln set up to monitor board-by-board drying rate. This service and the software are available directly from Forintek.

11.5 FUTURE TRENDS

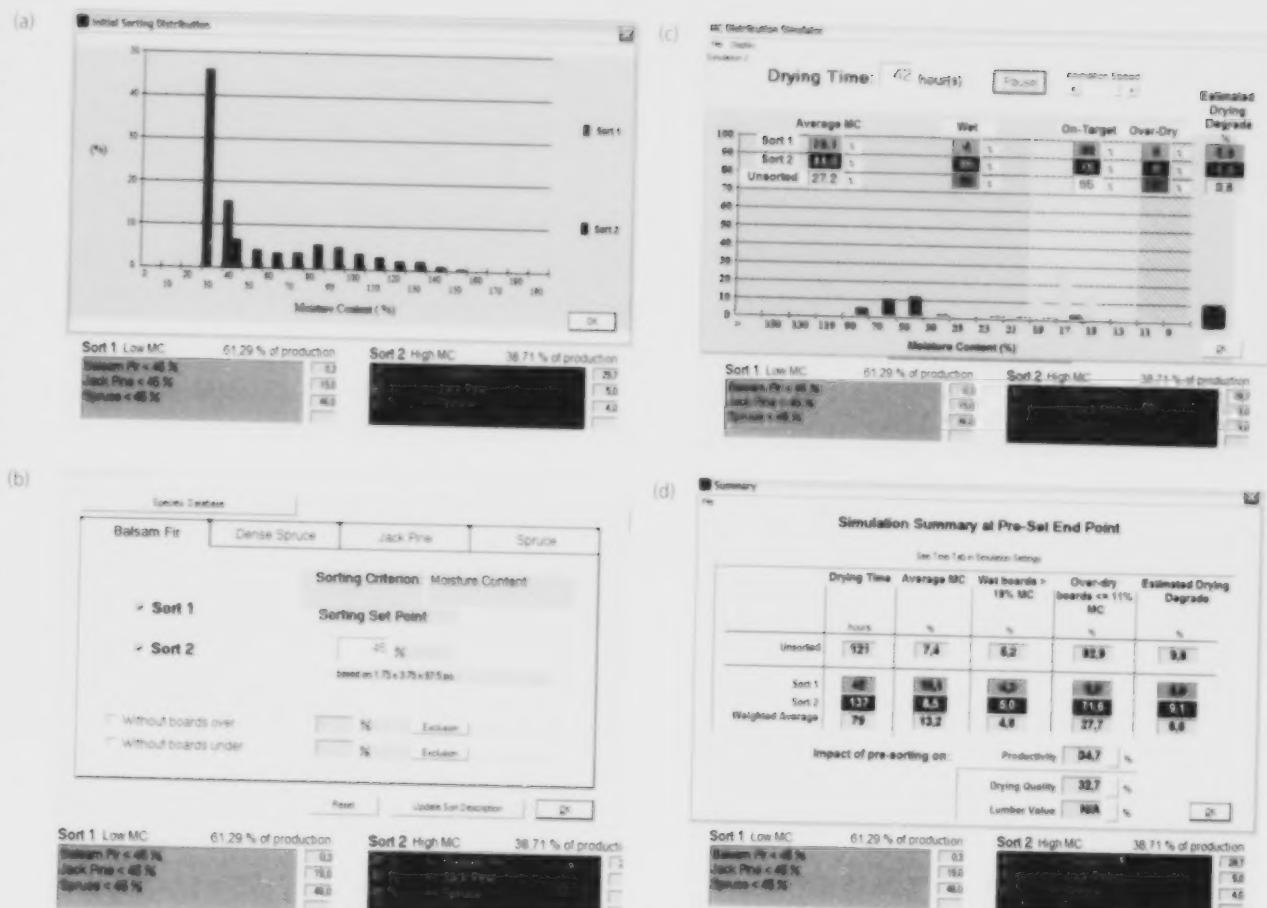
In relation to stringent quality requirements imposed by end-users, it is expected that rising production and energy costs will encourage the development of new systems and/or strategies to achieve better drying. Greater knowledge of material drying characteristics may also generate ideas for different sorting strategies using new innovative technologies.

An old concept that is receiving new attention is the idea of re-drying. In addition to pre-sorting, lumber producers should also consider and investigate the potential benefits of post-sorting "wets" from dried lumber to re-dry. To implement a re-drying program an in-line moisture detector (see Chapter 5) is used to sort lumber after drying. The concept of re-drying is attracting interest because it has the potential to both eliminate over-drying and increase kiln productivity. Decisions can be made to stop kiln loads prematurely. Lumber with a MC that is above its target is identified before the planer, separated, re-stacked and then either re-dried or

sold to a market that can tolerate a higher final MC. Lumber meeting the MC specifications after the first pass through the kiln continues on to the planer. This avoids having to over-dry the majority of a charge just to ensure that a small percentage of slow-drying material is at an acceptable MC. This is another strategy that results in increased kiln productivity, greater MC uniformity and improved lumber quality.

Figure 11-6

Forintek's OASiS™ software allows mills to evaluate various pre-sorting options in order to identify the optimum solution. These screen captures depict the various input parameters (a and b) and the output format (c and d) generated by the software.



PREPARING LUMBER FOR DRYING

12.1 OVERVIEW

The proper preparation of loads or packages of lumber and their assembly on kiln carts and in the kiln is essential for uniform drying. Any lack of conformance to the procedures described below will be at the expense of causing more drying degrade, widening the range of final MCs and extending kiln drying times, thereby causing excessive energy consumption and reduced kiln throughput.

12.2 RAW MATERIAL CONSIDERATIONS

12.2.1 LUMBER THICKNESS

Drying time increases disproportionately with thickness. A doubling of thickness results in more than a doubling of drying time. Even minor variations in thickness can have an impact on drying time or final MC variability. Size variation and mixing of lumber dimensions are therefore a concern when drying lumber.

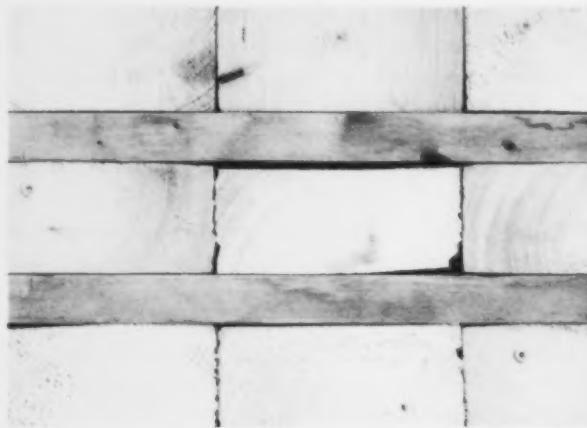
Some variation in lumber thickness is to be expected from normal sawing conditions, however, thickness variation greater than about 1.00 mm or 1/32-inch is usually a result of sawblade or feed problems in the sawmill. Thickness variation greater than this can have an effect on kiln drying SPF. Thick lumber dries more slowly than thin lumber, so mixing thick and thin lumber in a kiln charge increases MC variation. When drying in a high production environment it is not likely that you will be able to address this final MC variability by implementing an equalization treatment. Therefore, the only practical way to deal with the problem is to work toward minimizing size variations at the sawmill. Also, when thick and thin pieces are mixed across a course, the thinner pieces are not restrained by the stickers. This lumber is then free to cup, bow, crook and twist as shown in Figure 12-1.

Lumber with different target thicknesses should never be mixed (for example 1x6 with 2x6) in a kiln charge since clearly both over-drying of the thin and under-drying of the thick stock can occur. Considering the difference in

drying time and impact on quality it is usually more cost effective to dry two partial charges (each with a single thickness) rather than one charge of mixed thicknesses. The practice of "doubling" 1-inch boards with stickers only every second row, to simulate 2-inch stock is not recommended since when the kiln packages are broken down the boards will inevitably be wetter on the faces that were placed together, and may therefore cup upon further drying during storage, shipping or in service. Although stickering between every row results in less lumber in the kiln there is an offsetting reduction in drying time as well as an improvement in final MC uniformity.

Figure 12-1

Excessive lumber size variation results in un-restrained pieces within the pile that will be free to warp and contribute to drying degrade.



12.2.2 LUMBER LENGTH

The mixing of several lengths in the same load or package results in overhanging board ends as shown in Figure 12-2. The protruding board ends result in large gaps between loads and because air passing through these gaps by-passes the greater part of a load, overall circulation is reduced and drying time increased. On the other hand, while the greater part of the load is exposed to reduced circulation, the overhanging ends are exposed to an abnormally high volume of air, and dry consider-

ably faster than the bulk of the charge. This results in both non-uniform drying, extra warp, end-checking and a reduced volume of wood in the kiln.

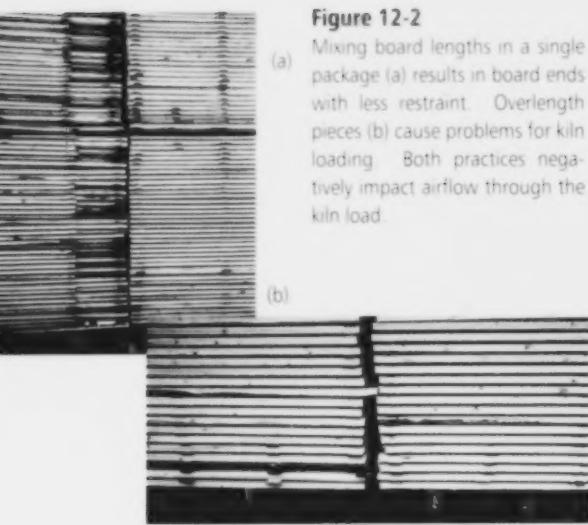


Figure 12-2

Mixing board lengths in a single package (a) results in board ends with less restraint. Overlength pieces (b) cause problems for kiln loading. Both practices negatively impact airflow through the kiln load.

In addition, because of lack of support and restraint, the ends are subject to warping (see Figure 12-2) and breakage.

Piling of mixed lengths is not recommended unless the material can be box piled. Box piling is used extensively in the hardwood industry where drying random length lumber is a normal practice. In this method the longest pieces are placed at the side of a pile in order to restrict the amount of air bypassing a load. Shorter pieces are placed on the inside and positioned alternately flush with one end or the other of the bundle. The technique of box piling is shown in Figure 12-3. This piling method not only eliminates overhanging ends but also results in squarer packages that provide a better base for upper packages either in the yard or the dry kiln. This results in less breakage of boards as well as less leaning and tipping over of lumber packages, and provides returns both in terms of improved lumber quality and improved safety. Automated stacking systems are available to handle mixed lengths and produce good-quality, box piled packages.

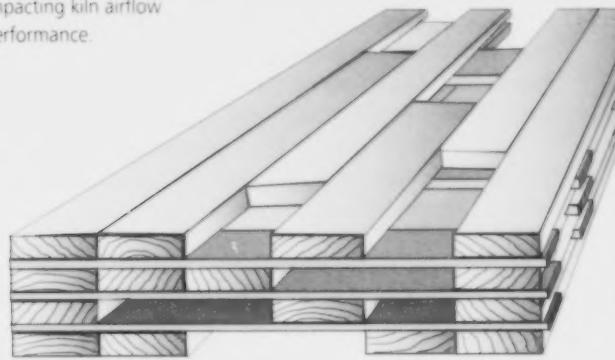
12.2.3 LUMBER WIDTH

Ideally, board widths should be uniform throughout a kiln charge, or at least not vary more than 2-inches, i.e., 4-inch with 6-inch wide, or 8-inch with 10-inch wide. This avoids the mixing of narrow width, high-MC sapwood with wider predominantly heartwood pieces which have a substantially lower green MC. Another reason for

drying uniform widths is to allow the operator to develop schedules specific to the needs of each width. As well as initial MC differences between material, as mentioned above, there may often be different final MC or quality objectives for different dimension material. For example, some mills will prefer to run a gentler schedule on wider widths to avoid too much over-drying and the resulting cupping.

Figure 12-3

Box piling is an effective way of providing good restraint to all pieces when piling mixed lengths without impacting kiln airflow performance.



12.3 PILING LUMBER

12.3.1 PILE PREPARATION

Piling or stacking lumber involves assembling boards in horizontal rows or tiers, each row separated by a number of regularly spaced strips or stickers. The spaces formed by the stickers are the passageways for the circulation of air. Lumber may be piled directly onto kiln carts which are pushed or pulled on rails into a kiln. This type of stacking which can be done manually or automatically eliminates the need for bunks at intervals up the height of the kiln load. All of the spaces are therefore sticker spaces and air circulation should be very uniform. Alternatively, lumber may be piled as packages which are stacked on top of each other by forklift to achieve the desired height. The thick bunks separating packages can, however, disrupt the uniformity of air flow.

Piling is one of the most important steps in the lumber drying process and it is important to note that all of the improvements in kiln designs and kiln schedules cannot offset drying degrade which originates by poor piling practices. The principles of piling are very simple.

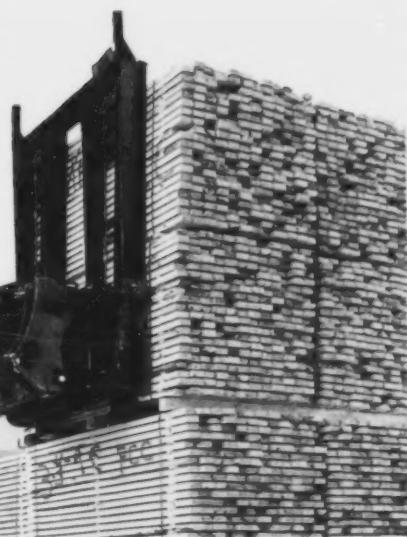
Stickers are placed at regular intervals (see section on sticker spacing) so that the rows of stickers are in perfect vertical alignment. The stickers should also be in alignment with the thicker supporting bunks below each

package and those, in turn with the bunks at ground level or supporting points on the kiln carts. In this way, all of the downward force is in a perfect line and there can be no tendency for boards to be forced out of shape due to misplaced stickers. Figure 12-4 illustrates these points. The sides of the pile should be as flush as possible, with no boards projecting beyond the others. Boards which do protrude will act as deflectors, causing more air to flow through some air slots and less air to flow through others.

Ideally, stickers should protrude by a small amount on both sides of the pile, regardless of the width of boards being piled. When stickers do not provide full support and restraint for edge boards, extra warp will develop. Given this, it is also important that stickers do not protrude too far. Stickers protruding by more than 1 to 2 inches (25 to 50 mm) are likely to get hung up on other packages when being placed in a storage yard or when being loaded for kiln drying. This again results in unnecessary breakage of stickers and increased warp in unsupported boards.

Figure 12-4

As shown here, stickers and bunks should be well aligned vertically to transfer weight from upper rows and provide good restraint to the lumber as it dries.



The outermost stickers should be placed as near to the ends of the boards as possible. This minimizes warp at the board ends, which tend to dry faster, and it also reduces the tendency for end checking. Problems can arise when handling long packages by fork-lift truck as the jostling and deflection of the lumber causes the end stickers to fall out. This can be overcome through the use of plastic strapping (see later section in this chapter) or by reducing sticker spacing in the lower six to eight rows to stiffen up the packages.

12.3.2 STICKER SIZING

Width

Stickers are usually $1\frac{1}{2}$ to $3\frac{1}{2}$ inches (38 to 89 mm) wide. If narrower than this, stickers can bite into soft lumber and this reduces the height of the air slot. If wider, the wood under a sticker may not dry and pockets of wet wood will be left along the lengths of boards. One important reason for having a sticker width distinctly different (usually greater) than the thickness is to make sure that there is no confusion, either by the equipment or operators, on how to place the stickers.

Thickness

Sticker thickness is a subject which attracts a lot of attention. There is always interest in reducing sticker thickness. Thinner stickers obviously result in more lumber in a kiln but if that lumber dries more slowly or less uniformly the problems created may be greater than the advantage gained. Some claim that drying is faster with thin stickers, while others have found results to the contrary. The most common sticker thickness is $3/4$ -inch (19 mm) followed by $5/8$ -inch (16 mm). By reducing sticker thickness more lumber can be placed in the kiln. For example, kiln capacity can be increased by approximately 5% by reducing sticker thickness from $3/4$ -inch to $5/8$ -inch.

Typically a kiln is designed to achieve a certain airflow based on sticker openings of a fixed size. Normally, this is about $3/4$ -inch (19 mm). Reducing the sticker thickness will also affect the physics of airflow in the kiln. The use of a thinner sticker may actually increase air velocity through the load but decrease the total volume of air. The thinner stickers create more air passages therefore, the air being circulated by the fans is divided up among a greater number of passageways. Consequently, the volume of air flowing between any two rows of lumber is less. The reduction in air volume results in a greater temperature drop across the width of the pile, less uniform drying conditions and greater variability in final MC.

The reduced opening size associated with thinner stickers will increase static pressure on the upwind side of the load which could also have a negative effect on fan efficiency. If you are considering the use of a thinner sticker on an existing kiln, problems will arise. If you are building new kilns and want to use a thinner sticker, this change should be discussed with the kiln manufacturer well ahead of time. The only way to compensate for the negative effects listed above is by installing a more powerful fan system to achieve higher air flow rates.

Uniformity in sticker thickness is as important as uniformity in lumber thickness. Piling lumber on a mix of thick and thin stickers will result in boards, or portions of boards, that have less restraint on them during drying.

12.3.3 STICKER MATERIAL

A variety of sticker materials are available, ranging from cheap in-mill generated green stickers to expensive, high-grade plastic and metal stickers. Which type is most economical for a mill depends not only upon initial purchase price but also on sticker life. For example, wide variations in lumber thickness and piling random-length lumber can distort and even break stickers. The manner in which stickers are handled and stored can also impact sticker quality.

Actual sticker costs can be determined by dividing the cost of a sticker by the average number of times it passes through the kilns. If new stickers are colour-coded, by painting the ends, they can be tracked to determine an average life-span. Thinner or narrower stickers may be less expensive on initial cost but if the life expectancy is short, a larger sticker may be justified from the longevity issue alone.

Green stickers, either hardwood or softwood, suffer from a number of disadvantages. Being green, they are inherently weak and soft in their first kiln charge and are therefore more prone to distortion due to uneven lumber thickness, and at the same time are less able to provide rigid restraint particularly in the uppermost rows of lumber. Stickers will shrink during their first kiln run, and the amount of shrinkage will vary according to factors including species, wood type and grain angle. In this way a unit parcel of uniform-size green stickers may quickly develop into a range of sizes, particularly thickness, which will thereafter provide poor restraint against warp in the lumber packages into which they are placed.

Some SPF mills produce their own stickers from kiln-dried stock. Ideally these should be sawn from select clears which are straight grained and have few knots. It is recommended that stickers not be made from lower grades since the presence of knots and cross grain result in excessive rates of breakage.

More expensive stickers include those made from phenolic resins or plastics, aluminum, steel and LVL (laminated veneer lumber). They have barely been used beyond the experimental stage, but LVL stickers show the most promise. They are uniform in size and MC when

purchased, and are reported to keep their dimensions better and warp less than solid wood stickers. A major disadvantage with non-wood stickers is the reduced friction between them and the wood. This causes problems with loads shifting especially when dealing with frozen lumber.

12.3.4 STICKER SPACING

It must be kept in mind that stickers serve a dual role in drying – that of providing an airspace between rows and that of providing restraint for the material to minimize warp. Both of these roles are affected by the spacing between stickers but it is the reduction of warp that is more significantly affected. It is clear that the more contact points between stickers and boards, the better the chance that those boards will be well restrained during drying. The challenge, however, has always been to determine the optimum sticker spacing that will minimize piling and sticker inventory costs and at the same time help avoid warp.

Softwood construction lumber mills use a wide range of sticker spacing. The most popular spacing presently seems to be 4 feet (1.2 m) with 3 stickers on an 8-foot (2.4 m) package and 5 stickers on a 16-foot (4.8 m) package. A few mills have gone to a 2-foot (0.6 m) spacing. A study conducted by Forintek identified improvements in lumber quality with most reductions in sticker spacing. In considering both the reductions in warp and the increased stacking costs, the following recommendations were developed:

- for regular grade softwood dimension lumber a sticker spacing of 32 inches (0.8 m) or less is recommended;
- for high-quality material, a sticker spacing of 24 inches (0.6 m) is recommended;
- also employ a 24-inch spacing (0.6 m) for material with a greater tendency to warp including juvenile wood, plantation stock, and material with a high incidence of compression wood and/or severe slope of grain (e.g., black/yellow spruce).

The Forintek study showed that on regular grade eastern SPF the percentage of pieces downgraded due to warp dropped from 2.2% to 1.3% as a result of reducing sticker spacing from 48 inches to 32 inches (1.2 to 0.8 m). When considering just superior grade products, with a much smaller tolerance for warp, the percentage of pieces downgraded due to warp was reduced from 71% to 49% by going to a 24-inch (0.6 m) spacing. To capitalize on this significant improvement in recovery of

higher-grade material a mill could consider separating this grade at the sawmill and piling it with a narrower sticker spacing.

Wood becomes more plastic when it is exposed to high temperatures. Therefore, the impact of missing stickers or misaligned stickers or bunks will be more pronounced when material is dried in a kiln versus an air drying yard and will be more severe again in kilns with higher drying temperatures. Doing all of the basics of piling correctly becomes more critical as drying temperature increases.

12.4 PILING WARP-PRONE LUMBER

Some SPF lumber is naturally warp-prone; for example, lumber sawn from juvenile wood near the pith is likely to twist, and lumber sawn from logs containing compression wood can develop crook or twist. Piling such material warrants extra care since if the lumber can be held perfectly flat and straight during drying, then there is an excellent chance that it will remain straight when it is down-piled, planed and put into service.

Stickers must be in perfect alignment and there must be more of them, one for every 2 feet (0.6 m) of lumber length. Sawing should be to very close thickness tolerances because a mixture of thick and thin pieces will result in the thinner pieces having no restraint from the stickers and they will be free to warp.

Lumber sawn from larger, mature logs seldom gives warp problems during drying but the utilization of smaller, younger logs can be expected to make this an increasing problem in the future.

When piling mixed dimensions or products in a kiln the more warp-prone material can be placed toward the bottom of the load to take advantage of the extra weight. For example, some mills experience more warp in 2x3s since they often originate from very small logs and have more warp-producing characteristics. On the other hand, wider boards are cut from larger logs that are often a better grade. In this case, the wider material could be placed on top of the narrower material to provide more restraint during drying. Mill staff need to make this decision themselves based on their knowledge of the warp characteristics and drying times of their different material.

12.5 KILN LOADING PRACTICES

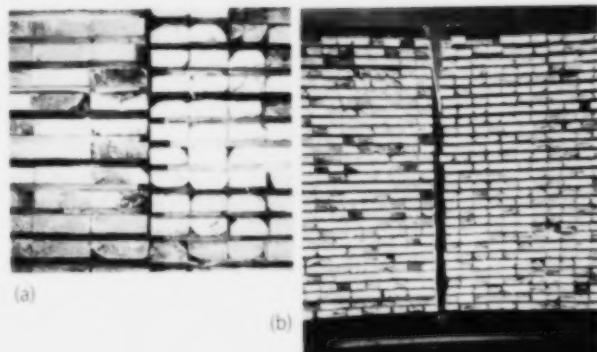
If possible, all packages stacked on top of each other and side-by-side packages in a track kiln should be of the same length. When this is not possible, the shorter pack-

ages should be placed on the top of the longer packages and on the side away from the top baffle. The top baffle will provide maximum air flow benefit if it is in contact with lumber the entire length of the kiln. If two shorter packages have to be positioned side by side in a track kiln, they should be staggered so that no voids are left to permit the air to short-circuit. If the void is left at the end of the charge, air can pass around the end baffle.

In some loading systems, stickers do not span the whole width of the pile. For example, a 9-foot (2.7 m) wide pile in a package-loaded kiln may consist of two, 4.5-foot (1.4 m) wide packages side-by-side. In these situations, some air slots in one package may not line up with those in the adjacent package (see Figure 12-5a). This causes a great resistance to air flow through both packages reducing the air velocity and slowing the drying rate. To overcome this problem a vertical chimney 2 to 3 inches (51 to 76 mm) wide must always be left between the packages as shown in Figure 12-5b. This way the air can move easily from the exit side of the air slots of the first package to the entry side of the air slots of the second package.

Figure 12-5

When sticker openings do not align (a) airflow is impeded and will cause problems with extended drying time and/or increased variability in final MC. The problem is rectified by maintaining a chimney of 2 to 3 inches (51 to 76 mm) in width between packages (b).



12.6 TOP RESTRAINT

Most losses from warp occur in lumber near the top of the lumber pile since that lumber has little or no weight above to hold it flat. To save this lumber from degrade, weights in the form of concrete slabs or blocks or steel I-beams can be placed on top of the loads. A number of hydraulic, spring-loaded clamps have also been suggested. To be effective they must be capable of maintaining pressure on the load as it shrinks in height due to thickness shrinkage of individual boards during drying.

A Forintek study on this subject identified that warp losses in the upper 10 to 15 rows of unrestrained material were, on average, twice as high as that in the rest of the load. To prevent this, a top restraint in the order of 100 pounds per square foot (500 kg/m^2) is recommended. This equates to approximately 8 inches (20 cm) of concrete or 2.4 inches (6.1 cm) of sheet steel. Figure 12-6 shows the placement of concrete weights on a load of SPF lumber. The savings associated with a reduction in warp must be balanced against the extra costs in order to make a judgment of whether or not this is economically viable. Extra costs are incurred from a reduction in the number of rows of lumber in the kiln, the cost of the weights, and the extra time to handle, place and remove them from the load. Another consideration with dead weight on top of a load is the potential safety hazard if equipment is not set up to handle the extra weight and guard against movement. Figure 12-7 shows a mechanical restraining system incorporated into a kiln. This type of device may not work in every situation but where it does, it removes some of the disadvantages associated with top restraint mentioned above.



Figure 12-6

A Forintek study has shown that approximately 100 lb/ft² (500 kg/m^2) of weight on top of a kiln load (8-inch thick concrete in this example) will reduce drying degrade in the upper rows of the kiln load.

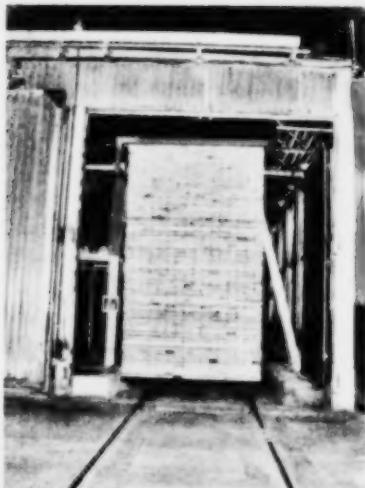


Figure 12-7

Top restraint can also be achieved by means of a mechanical device as shown here. The device must be able to constantly adjust to maintain restraint as the load dries and shrinks.

12.7 PLASTIC STRAPPING

Placing plastic straps around green bundles of lumber at the sawmill has been suggested as an alternative to top restraint. Plastic strapping products are now available that can accommodate a certain amount of stretch in order to adapt to the shape and size of shifting packages as well as the shrinkage that occurs during drying. A number of mills in Eastern and Western Canada have implemented this measure and have realized benefits other than reductions in warp. Based on experience at these mills, the main benefits attained are from a reduction in pieces lost from packages during handling in the yard. Another benefit stems from better maintenance of package integrity from the sawmill to the kilns. Square packages mean better restraint for all pieces within the load. The better secured packages can be handled more readily, increasing productivity with the fork lifts. Although the straps apply a considerable amount of compressive force to the load they do not reach the same level of restraint as a full top restraint system would. However, the restraint that is applied is enough to achieve some benefit from a reduction in warp.

Plastic strapping systems can be quite simple and applied manually with handheld equipment or fully automated. Fully automated systems can incorporate some sort of package compression system to compress the package in both the horizontal and vertical directions prior to applying the strapping. Other variables to be considered in implementing a strapping system include the grade or gauge of strapping, which can affect the tensile load that can be applied, and the number of straps to apply per package. Some mills have opted for a single strap whereas others have gone with two. In either case the strapping must be applied either over or adjacent to one of the vertical lines of stickers. A single strap will help maintain package integrity but will not have a lot of impact with regard to warp reduction.

The plastic strapping is removed only after the packages reach the planer mill and therefore it also provides protection against loss of material between the kilns and planer. The used strapping is chopped up and returned to the manufacturer for recycling.

Some mills have tried using metal strapping but this typically becomes loose with the first handling after leaving the sawmill and quickly loses its effectiveness other than to stop boards from falling out of the package.

AIR DRYING

13.1 OVERVIEW

Whether you realize it or not, you are involved in air drying your lumber. Unless every board leaving the sawmill makes it into the dry kiln within a few days of being sawn it does get exposed to some drying from the natural elements. If the material is managed and handled properly there is potential benefit from any drying that takes place at this stage. On the other hand, if care is not taken, it can complicate the situation for the kiln operator when the material arrives at the kilns. Significant drying can take place at certain times of the year and if this is achieved in a uniform manner it can help reduce kiln residence times, reduce energy consumption and even reduce drying degrade.

When producing SPF products such as dimension lumber, the final MC requirements of 12 to 19% can realistically be reached in a well-managed air drying yard, avoiding the need for dry kilns. Other considerations, however, such as inventory reduction, on-time delivery and phytosanitary (heat treatment) requirements often dictate that air drying is, at the most, a supplementary drying system. Achieving uniformity in drying at this stage will produce a more easily dried product for the dry kilns. Following the basics described in the next sections will help achieve a better degree of uniformity.

The following situations are examples of where air drying can realistically be used to advantage:

- pre-drying of a wetwood species such as balsam or subalpine fir;
- pre-drying material at times of the year when the kilns cannot maintain pace with the sawmill;
- drying material that is to be used domestically and does not require heat treatment;
- post-drying of "wets" remaining in a charge after an initial kiln drying treatment.

13.2 THE BASICS OF AIR DRYING

13.2.1 LUMBER PILING

Good piling is as critical for air drying as it is for kiln drying. Proper alignment and spacing of stickers and bunks, as described in the previous chapter, will help reduce warp and promote airflow.

Stickers of less than 3/4-inch (19mm) can sometimes be accommodated in a dry kiln, assuming that the airflow system is designed around it. In an air drying yard however, thin stickers are an impediment to airflow. With a thinner sticker there is a greater resistance to air flow, causing slow drying and quick saturation of the air as it passes through the load. If air drying is relied on as part of the overall drying program, stickers should be no less than 3/4-inch thick. The main advantage from a thicker sticker will be the promotion of more uniform drying.

Securing packages of green lumber with one or two plastic straps at the sawmill will help maintain package integrity. This topic is discussed in more detail in the previous chapter. When air drying, there is sometimes a need to handle the lumber more often and transport it over longer distances in the yard. Under these conditions, plastic strapping will prove beneficial.

13.2.2 YARD LOCATION

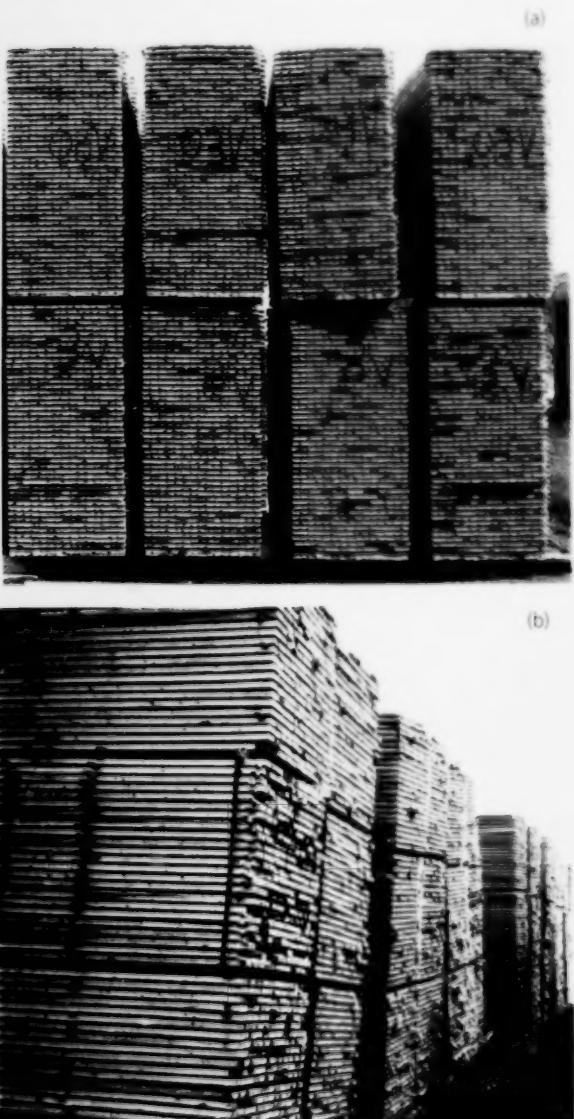
The first step in setting up a successful air drying operation is to select a good location. There are several aspects of location that are important. First of all the site should be located so that it is well exposed to the prevailing winds. A yard located close to large buildings, next to a forested area, or other natural barrier will not achieve good air flow and therefore will dry more slowly and/or less uniformly. The ideal location for an air drying yard is an elevated area, away from obstacles.

A second important aspect of yard location is choosing a site that is well drained with a firm base. Figure 13-1 shows the difference between a poor and a good base.

Poorly drained areas are more prone to frost heaving in the winter and sinking in the spring, both of which can cause loads to lean and even tip over. This is a safety concern as well as a quality and productivity issue. If a good natural base is not available, some time and effort should be made to prepare such a site. Very few mills can afford to pave their air drying yard, but adding a good quality fill or gravel will help keep both roadways and piling areas level and smooth. Not only does this provide a stable base for packages but it also promotes faster handling of material in the yard and better package integrity.

Figure 13-1

As shown a well leveled yard and firm base (a) will facilitate package placement and spacing. Leaning packages (b) not only are a safety hazard but contribute to uneven drying and extra drying degrade.



13.2.3 YARD ORIENTATION, PREPARATION AND MAINTENANCE

Once a smooth level site has been selected, the next step is to lay out a piling pattern and prepare pile bottoms to accept lumber. There are two principal patterns for configuring an air drying yard — line and row arrangements. Figure 13-2 shows the placement of packages in both types of yards. They can be compared to a track versus package-loading kiln not only in package arrangement but also in the effect of each on drying.

In a line-type yard, the distance of air flow through the lumber stack is quite short, and more uniform drying can be expected. Whereas in a row-type arrangement, the air must pass through much more lumber and some variation in drying rate can be expected. A row-type yard should be limited to no more than 5 to 7, 4-foot (1.2 m) wide packages between roadways. More than this will make it difficult to access material and will impede airflow. The impact of distance of air flow is minimized in both yard arrangements by leaving approximately 2 feet (0.6 m) between packages. This provides a means of injecting some fresh, relatively dry air into the air stream.

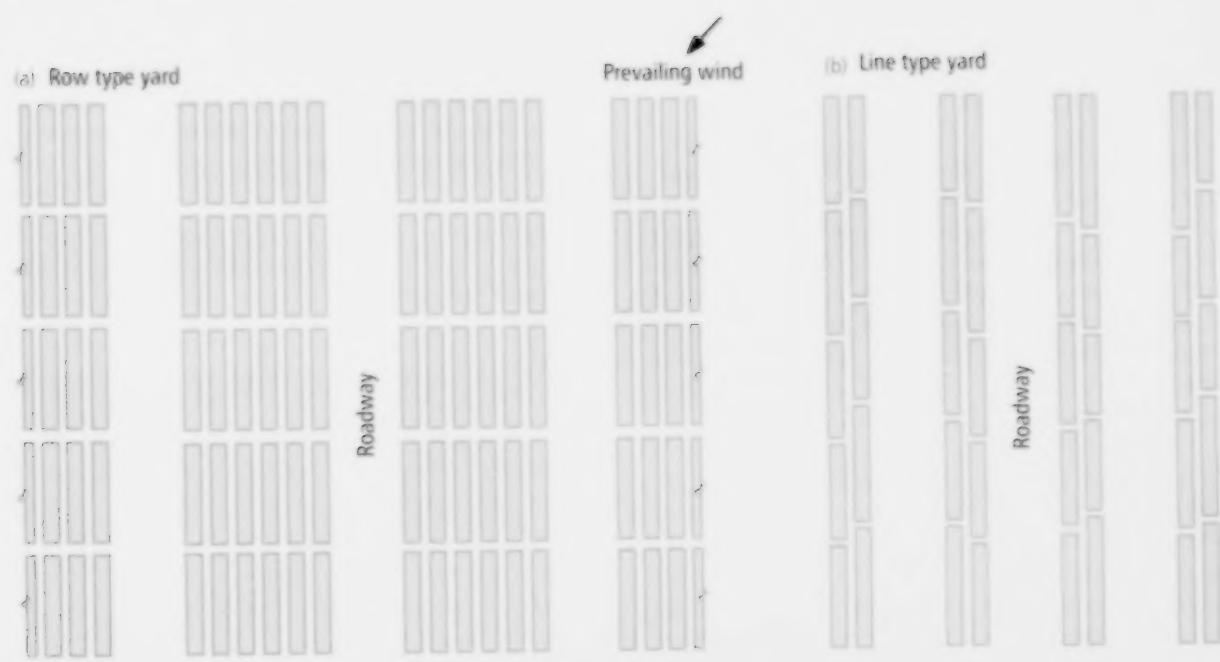
The orientation of the packages in relation to the prevailing winds is another factor that must be considered. Although there are different theories, placing the packages at a slight angle to the prevailing winds as shown in Figure 13-2 is the best compromise. The wide face of the package should be almost perpendicular to the wind so that most of the air hits the sticker openings. The angle helps ensure some infusion of new air into the spaces left between packages. In areas with heavy snowfall, it is often desirable to orient the yard so that the spring sun shines along the alleyways left between packages. This will help melt snow and allow early springtime drying. In many cases these last two considerations may conflict, in which case a good compromise should be identified.

There are some other factors to be considered in deciding to build a row or line-type yard. With a line yard, all material can be accessed at any given time. However, in a row-type yard, material can be blocked in, and if good inventory practices are not maintained, a "first in, last out" situation can develop. This defeats the main purpose of air drying, which is to reduce the MC to a lower and more uniform level before kiln drying. For a given volume of lumber, a line yard will require more land area but the advantages of uniform drying and ease of inventory control may justify the extra cost.

Pile bottoms can be made from wood, concrete, steel, or combinations of these materials. In an ideal setting, the

Figure 13-2 a & b

Air drying yards can be set out in a row configuration (a) or a line configuration (b). There are advantages and disadvantage with each as discussed in the text.



lower portion, or main supports for the pile bottoms, would be permanently placed. This helps ensure consistent placement of packages with regard to the recommendations mentioned above concerning orientation and spacing. The pile bottoms should be at least 12 to 18 inches (30 to 45 cm) high to provide good air flow below the packages and provide greater assurance that no packages come into contact with the ground. If material is being kept for a long period of time it may be necessary to cut or spray weeds or grass to ensure they do not block air flow below or through the lower courses of wood.

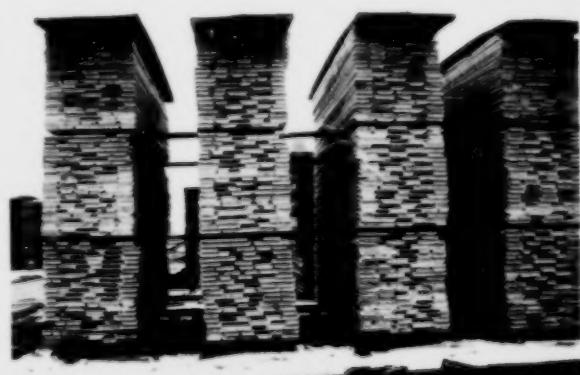
In line-type yards, the number of packages between roadways is limited to two. As mentioned above, the number of packages between roadways in a row-type yard should not exceed 7, 4-foot (1.2 m) wide packages. Jamming a larger number of packages between roadways results in poor air flow and a large variability in drying rate between packages located near the outside of the pile and those sandwiched in the middle. This again contributes to non-uniform drying and could result in supplying a lumber mix to the kilns that will be more difficult to dry than fresh green material.

Longer bunks or additional bunks can be used to bridge between two adjacent rows of bundles (as shown in

Figure 13-3). This will provide greater stability for the individual rows and help reduce leaning or falling over of lumber piles. Pile covers are used in some yards either when material is being stored for extended periods or in locations that receive significant amounts of rain or snowfall.

Figure 13-3

When material is to be left in an air drying yard for an extended period, the use of pile covers will protect the wood from re-wetting and bridging bunks will help prevent pile tipping.



13.3 MONITORING AND INVENTORY CONTROL

All packages should be tagged, or otherwise marked, to indicate when they were placed in the air drying yard. This will facilitate the assembly of kiln charges of even-aged material. A paper or computer mapping/inventory system can be set up to quickly identify age and location of all material in the yard.

Aside from maintaining inventory records it is still important to conduct visual inspections of material in the yard on a regular basis. During a walk around the yard look for any bad practices related to piling or placement of packages in the yard. Also look for signs of slow drying, such as mould or blue-stain beginning to develop on pieces, especially between rows of bundles. Although severe end checking is not desirable, no sign of any end checking is probably an indication of overly slow air drying.

Monitoring of drying rate in an air drying yard is difficult. There are no practical ways of obtaining information on MC and MC changes when the material is significantly above the fibre saturation point (FSP = 25 to 30% MC). Once the material starts to approach the FSP, handheld moisture meters can be used to get a rough approximation of the wood's MC. This is useful in those situations where the objective of air drying is to remove some or all of the free water.

There is also the possibility of using wireless transmitters attached to DC-resistance probes to determine when a target MC has been met in an air drying yard. These devices are used in dry kilns for this same purpose but their application has been mostly limited to hardwoods and high-valued, softwood products. For mills trying to optimize their productivity this tool could help assure better consistency of material going into the kilns.

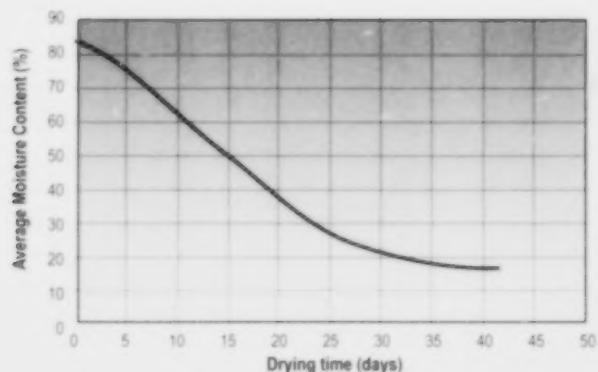
13.4 RATE OF DRYING IN AN AIR DRYING YARD

One of the ways of addressing the wet pocket issue in subalpine and balsam fir (see Chapter 4) is to air dry this material down to a MC where it will dry in a similar manner and time to spruce and pine. A Forintek study investigated this approach specifically with regard to its application on Eastern balsam fir. It was possible to air dry balsam fir from a green condition to approximately 18% MC over a 16-week period commencing in early April at a mill in South-eastern Quebec. As in many locations across Canada, the best air drying conditions tend to be in April and May when there is good air movement and low relative humidity. Figure 13-4 shows the observed air drying rate for balsam fir from this study. Under

spring and summer conditions, material over 35% MC dropped slightly more than 2% MC per day in a good air drying yard. As with kiln drying, the drying rate slows considerably once the wood approaches the FSP. These tests showed that balsam fir could be air dried to approximately the FSP in about 8 to 10 weeks under summer conditions. At this point, the material can be placed in a conventional kiln and dried on a schedule similar to that employed for normal green spruce or pine.

Figure 13-4

Drying rate of 2-inch (51 mm) thick balsam fir lumber in an industrial air drying yard in south-eastern Quebec.



Final MC uniformity is the main benefit achieved from air drying. In the test described above, kiln drying balsam fir from the green condition resulted in a standard deviation on the final MC of 8.6%. By air drying to the FSP and then kiln drying, the standard deviation on final MC was reduced to 5.7%. When the material was air dried completely to the target MC of less than 19%, the standard deviation was reduced to 2.4%. When dried in combination with spruce and pine, a pre-air drying treatment for fir reduces the tendency to over-dry these other species. Less over-drying results in less shrinkage and warp and therefore less downgrade and value loss due to drying.

Virtually all of the SPF producing regions of Canada experience significant winter conditions for at least a few months of the year. The assumption has always been that material placed in the yard does not air dry during the winter months. The tests described above demonstrated that, although drying rates were slowed considerably, the material did dry under winter conditions. For high MC material, the average drying rate under winter conditions was approximately 0.6% MC per day. There-

fore, placing high MC balsam or subalpine fir in the air drying yard in the winter will still achieve some drying. The best scenario is to place this material in the yard during the winter and leave it there through the early spring period when drying conditions are at their optimum.

13.5 SUMMARY OF RECOMMENDATIONS RELATED TO AIR DRYING

1. Air drying does make an effective pre-treatment for balsam and/or subalpine fir and, in some cases, allows this material to subsequently be dried on a normal spruce and pine schedule.
2. Due to slow drying below the fibre saturation point and phytosanitary requirements, air drying is not a viable total drying option but does work well in conjunction with some form of elevated temperature drying system.
3. Proper air drying practices need to be followed to maximize drying rate and ensure uniform drying of all material.
4. An air drying yard can serve as an equalization treatment for "wets" segregated after an initial kiln run.

MONITORING THE KILN DRYING PROCESS

14.1 LUMBER CONDITIONS BEFORE KILN DRYING

Knowledge of the history and, in particular the moisture condition of the material entering the kiln is valuable when determining what drying conditions to apply to a given load. Chapters 10 and 11 provide an overview of variables that need to be considered when tracking and handling material prior to the kiln. The next step in the information process is to be able to gather and interpret information during the drying process in order to make the best decisions possible. Most industrial drying processes for SPF dimension lumber do not lend themselves well to human intervention either due to the physical conditions in the kiln or the shortness of the drying cycle. Therefore, practices applied in other lumber drying situations may not work well or will have limited use for SPF drying. Information collected before and during drying will help the operator make the best decisions with regard to the application of drying schedules which are covered in Chapter 15.

One way to gather some information on the starting condition of the load is to use a DC-resistance meter to sample MCs along the edge of the kiln load. This can be done either before the load is placed in the kiln or after it is pushed/loaded in the kiln but before starting the kiln. Although the absolute MC levels measured at this stage are not very accurate, they do provide some insight into the condition of the load, especially if some air drying has taken place. With some experience, an operator will learn to detect differences between spruce/pine versus balsam/subalpine fir. In this manner they can get a measure of the relative proportion of each in a kiln load which could help with schedule selection or better estimating the required drying time.

14.2 TECHNIQUES FOR MONITORING PROGRESS OF DRYING

14.2.1 LUMBER-WEIGHT METHODS

14.2.1.1 LOAD WEIGHT

Laboratory test kilns are frequently designed so that an entire load rests on a weighing system allowing weight loss to be measured continuously throughout a run. If a reasonably accurate measure of the initial average MC for the load is made, the changes in load weight can then be used to calculate subsequent average MC values for the load.

Similarly, a few kiln manufacturers have incorporated systems to measure an entire package or kiln cart of lumber. The information on package weight can be utilized in several ways. As described above if the initial MC of the wood is known, the subsequent weight changes can be related to MC changes. The rate of weight change may be an indicator of the status of the charge. Since drying rate steadily declines throughout the process, achieving a certain rate of weight loss may be a good predictor of intermediate or end-point MC. Another technique would involve knowing the specific gravity and volume of material in the portion of the load being weighed. Specific gravity could either be taken from the literature (see Chapter 3) or an average value determined for the range of material being processed. If the weight, specific gravity and volume of a piece of wood is known, it is a relatively simple calculation to determine the initial and any subsequent MCs. Procedures to relate specific gravity, weight and MC are described in Chapter 3.

14.2.1.2 SAMPLE BOARD METHOD

An approximation of the load weighing method is referred to as the sample board technique. This technique involves using selected sample boards from a load and monitoring their individual weight losses. It is employed widely in the hardwood industry for high-valued products requiring long drying times. It can also be applied in drying high-grade softwoods where long schedules are used, hence it is described here. Another potential application in the softwood dimension lumber industry is as a tool to help develop drying schedules. The method consists of placing a number of prepared sample boards in a load to be dried so that they can be withdrawn at

various intermittent times, and weighed to estimate their MC.

Boards from which samples are to be cut, should ideally be selected while the lumber is being piled for drying. The boards selected should be representative of the driest and wettest, thickest and thinnest, edge-sawn and flat-sawn, and from boards containing varying amounts of sapwood and heartwood. At least 18 to 24 inches (46 to 61 cm) should be trimmed from each end of these boards. The next 1-inch (25 mm) along the grain is then cut off to obtain a MC section. The cutting procedure for a sample board is shown in Figure 5-1 in Chapter 5. The remaining portion of the board will form the sample board to be placed in the load. It should be no shorter than 2 to 3 feet (0.6 to 0.9 m) in length. Neither the MC sections nor the sample boards should contain pitch pockets, rot, knots or large amounts of bark.

Sample boards should be end coated with an impermeable coating such as roofing tar, silicone sealant, or a very thick paint to prevent end drying. The most practical placement of samples boards is somewhere in the opening created by the supporting bunks.

Each time the sample boards are removed they are weighed and their MCs are calculated as described below:

Step 1:

Calculate the average MC of each sample board by oven drying the two small sections and using the procedure described in Chapter 5 to determine their individual MCs. Average the two MCs to determine an "Average MC" for the sample board.

Step 2:

For each sample board calculate its predicted oven-dry weight according to the formula:

$$\text{Predicted Oven-dry Weight} = \left\{ \frac{\text{Green weight of board}}{(\text{Avg. Moisture Content} + 100)} \right\} \times 100$$

Step 3:

Each time a sample board is removed during drying, it is weighed and its new weight used to calculate an intermediate MC using the following formula:

$$\text{Intermediate MC (\%)} = \left\{ \frac{(\text{Intermediate Weight} - \text{Predicted Oven-dry Weight})}{(\text{Avg. Moisture Content} + 100)} \right\} \times 100$$

Changes can then be made in schedules when either the average of the MCs of all the sample boards reaches a change point, or when the wettest sample board reaches a change point.

It will be obvious that the sample board method would be difficult to use in situations of high productivity with short drying cycles. In addition, since access to the kiln is necessary, it can only be used when the kiln temperatures are low enough to permit entry; and the method cannot be used in direct-fired kilns where burner emissions create an environment dangerous to humans.

A major drawback to this technique lies in the number of samples that can be tested, and in how representative they are of the total load. A sample of 12 boards out of 50,000 or more in a load may not be truly representative. Added to this is the fact that where the samples are placed in the load will represent the drying conditions only at those locations in the kiln.

A potential application of the sample board technique in a high-speed softwood drying operation would be as a tool to develop or test drying schedules. The drying rate information that can be obtained is useful in identifying where to make changes in a drying schedule. In this manner sample boards could occasionally be used to develop new or to optimize existing drying routines.

14.2.1.3 IN-KILN SAMPLE BOARD WEIGHING

Another way of implementing the sample board technique is by automating the process of collecting intermediate board weights. Electronic load cells have been developed that will tolerate and work well in a kiln environment. One obvious application has been to replace the manual weighing of sample boards when drying high-quality woods. There are several kiln instrument manufacturers offering this type of control system. Once the technical hurdles of weighing a sample in a dry kiln have been overcome, the concept is simple, accurate, and straightforward. Load cells are available that cover a wide range of operating temperatures but there are limits either imposed by the technology itself or cost.

The advantages over a manual sample board system are continuous weighing rather than spot checks and the possibility of weighing samples in an environment inhospitable to a human operator (direct-fired kilns). The operator must still manually select and set up the sample boards as in the past, but they are now placed in an apparatus either on or suspended from load cells to continuously monitor individual sample weight.

14.2.2 ELECTRONIC METHODS

14.2.2.1 DC-RESISTANCE PROBES

Lumber MC can be estimated using the DC-resistance principle and sets of electrodes inserted into predrilled holes at one or more depths in each of a number of boards in the kiln charge. The principle of measurement is almost identical to that of hand-held moisture meters described in Chapter 5. A major limitation of this type of monitoring is the inherent inaccuracy of resistance-type systems above fibre saturation point (FSP), and the need to make temperature adjustments to the readings obtained. In a computerized system the temperature adjustment can be taken care of automatically.

Again, as with the above weight-based sample board method, the selection of sample boards to adequately represent the entire load, and their location in the load, clearly influence the accuracy of the system. One method to screen boards and make a final selection is to use a handheld DC-resistance meter. By pinning a larger number of boards, a smaller sample can be selected that still represents the range of material present in the entire load.

This method can be used not only as a feedback system to assess progress of drying, but can also be incorporated into a continuous fully automatic kiln control processor. Many operators will use the DC-resistance estimates of MC as only one of two or more means of predicting final MC in order to make a decision on when to terminate drying.

Figure 14-1

Some kiln controllers and independent MC monitoring systems utilize DC-resistance probes placed in boards within the kiln load to monitor drying rate and/or determine end point.



14.2.2.2 DIELECTRIC PROBES

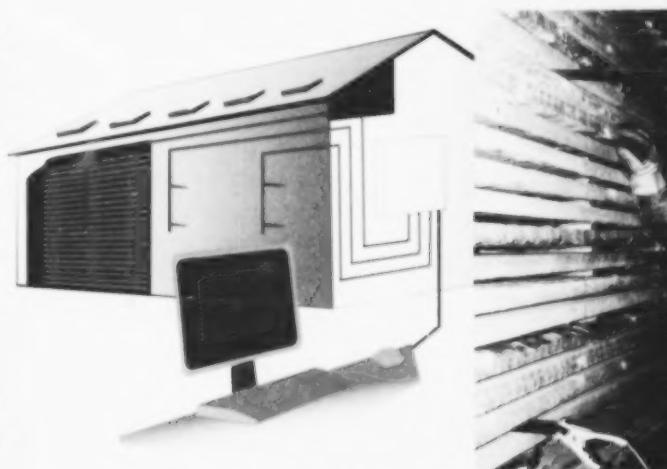
Several manufacturers are now providing an in-kiln moisture sensing system that measures the dielectric properties of an entire bundle (or large portion of a bundle) of lumber. The sensors of these systems typically consist

of a pair of metal strips that are slid through the sticker openings (see Figure 14-2). Each kiln can be fitted with multiple sensors to obtain MC estimates from various areas of the load. The metallic sensor strips are spaced at a pre-determined distance (i.e., specific number of rows) apart. This typically results in 200 or more boards being contained within the sensing zone.

This type of in-kiln moisture detector provides a single MC estimate for each sensor. This MC estimate is intended to represent the average MC for all of the material in the sensing zone. How well that value represents the actual MC depends to a large extent on how well the system is calibrated.

Figure 14-2

An example of an in-kiln MC monitoring system based on a dielectric principle and using probes that extend through part of the kiln load.



Most systems can accommodate 8 or more sensors per kiln. The data is fed to a central computer that can be used to monitor multiple kilns. The readings are collected on a continuous basis and therefore a drying curve is generated for the material in each sensing zone. The primary application for the MC data is to serve as an operator assist in determining the most appropriate time to shut the kiln down. The ultimate benefit should be a reduction in the number of charges that are either under- or over-dried. A more consistent final MC means less downgrade from warp, associated with over-drying, or "wets", resulting from too short a drying cycle. Another possible application of the information is to assist in operating the kiln by providing intermediate MC values that help the operator determine when to make schedule changes.

Taking more time and effort to calibrate the system will help achieve more consistent results and a faster payback on the investment. The following suggestions are provided as a guide on how to approach the process of calibrating a new in-kiln moisture detector.

- First, determine the base line to which results will be compared. In many mills this is likely to be the in-line moisture meter at the planer. If this is the case, make sure that the in-line meter has also been properly calibrated and is in good working order before beginning the process of calibrating the in-kiln detector.
- In order to calibrate against an in-line moisture meter it will be necessary to capture data from individual kiln charges as well as lumber originating from each of the sensing zones being monitored. In this manner, it should be possible to develop correlations among individual probe readings (taken at the end of the kiln run) and average MC data from the in-line meter from the sampling zone. Likewise, it will be possible to eventually develop correlations between the average of all the final probe readings from a given kiln charge with the average MC data from the in-line meter for the entire charge of lumber.
- Without an in-line meter, it is still possible to develop the same types of correlations but it will take a little more effort. Separate material from each of the sensing zones can be identified for MC measurements using a hand-held meter. For data on the entire charge, spot checks on it can be conducted as it is being processed at the planer mill.
- For improved overall accuracy, one of the mill moisture measuring systems should be calibrated against oven-dry determinations of MC. The oven-dry procedure is the most accurate procedure available and provides the best base line for any moisture meter. In a mill with an in-line meter it can be calibrated against oven-dry results. Other systems, such as the in-kiln meter, could then be calibrated against the in-line meter. An important consideration is to make sure that whatever is done is tied in with the system that is ultimately being used to judge the final MC of the product. This could include sampling procedures or correction factors that are specific to the products being produced or customer being served.

The main disadvantage of this type of in-kiln moisture sensor is the absence of data related to final MC variability. It may be possible to obtain improved information with regard to average MC for the load but these systems do not provide any board-by-board MC data. If drying material that has very consistent final MC char-

acteristics, this may not be so important. However, in many cases it is the standard deviation (variability) on the final MC that determines when a load can be pulled. If this is the case, then it may still be necessary to conduct a hot check with a handheld meter capable of obtaining board-by-board data.

14.2.3 TEMPERATURE DROP ACROSS LOAD (TDAL)

Temperature drop across the load (TDAL) is a parameter used by several manufacturers and is a measure of the amount of energy given up by air in evaporating moisture as it passes over wet wood surfaces. Typically most woods will produce a large temperature drop across the load at the start of drying with this value becoming smaller as drying progresses. With experience, a given temperature drop across the load value can be interpreted as an end point in drying and an indicator of when to shut down a kiln.

In order to use TDAL effectively, the value must be correlated against some other system. The procedure described in the previous section on calibrating an in-kiln device can be used to develop correlations between final TDAL values and final MC values observed at the planer mill. TDAL is affected by a number of other variables and it will therefore be necessary to develop correlations for a number of different operating conditions. This would include different drying schedules, different products in the kiln, and especially different airflow characteristics.

14.3 TECHNIQUES FOR DETERMINING THE END POINT IN DRYING

Determining when a kiln charge is dry is critical to successful kiln drying. Under-dried lumber has a MC that fails to meet standards and is usually unsuitable for its intended end use. Over-drying increases the likelihood of drying degrade as well as wasting energy and production time.

Each of the above methods can be used to estimate drying end-point but the following conditions and requirements apply.

14.3.1 SAMPLE BOARD METHODS

Whether weighed manually or with an in-kiln system the success of these methods depends on the initial board selection being representative of the load, placement in the load, not being in 'cold-spots' or 'hot-spots' in the kiln, and frequent measurement towards the end of a drying cycle to avoid over-drying.

14.3.2 IN-KILN DC-RESISTANCE PROBES AND DIELECTRIC PROBES

Both these methods can be used to estimate end-point MC provided that adequate care is taken to correlate readings against measurements taken at the planer mill. In the case of DC-resistance it is important to apply correct wood temperature adjustment factors. Even if this is done automatically the appropriateness of the factors applied should be verified. Final wood temperatures will be very close to the kiln's dry-bulb temperature, but the actual values can only be determined if a temperature probe such as a thermocouple is also inserted into the sample boards.

The accuracy of these methods will improve as data from successive runs are accumulated and the kiln operator gains experience by comparing with feedback from moisture checks subsequently carried out on loads after removal from the kiln and cool-down are completed.

14.3.3 TEMPERATURE DROP ACROSS LOAD (TDAL)

TDAL values drop towards the end of a drying cycle since less energy is consumed in evaporating moisture from the wood. Exactly what TDAL value is used in estimating end-point can only be learned from experience, and as with other methods must be correlated with data later obtained from quality control checks of dry dressed lumber. Record keeping is of primary importance to allow confident interpretation of TDAL data.

14.3.4 HOT CHECKS

A hot check entails using a hand-held moisture meter to estimate the MC of a load of lumber still in a kiln. The "hot" portion of the term refers to the temperature of the wood at the time of the test. The reason for conducting a hot check is to determine whether or not a particular kiln load has reached the desired final MC. Sometimes this test may be simply a double-check on information obtained by some of the other measures described above. In other cases it may be the only check on final MC. The reason for conducting this test while the wood is still in the kiln is that if the wood is not dry enough the kiln can be re-started to complete the process. There are safety considerations when conducting this test. Management and the kiln operating staff must establish safe operating practices. These practices will vary from mill to mill depending on the nature of the kiln equipment but the following points should all be considered:

- lowering the temperature to a "safe" and reasonably comfortable level;

- if the kiln is direct-fired, implementing some procedure to ensure that the kiln is well aired out before anyone enters;
- putting in place measures to prevent or guard against loose boards falling off the load;
- locking out the kiln to prevent its operation and informing a co-worker that someone is in the kiln.

There is no one preferred tool for conducting a hot check. Both DC-resistance meters and dielectric (RF) moisture meters can be used. In general, a DC-resistance meter works well for uniformly drying species and a dielectric meter for wet pocket-prone species. When sampling a wet pocket species it is important to get a large sample of readings and this is more easily done with a dielectric meter.

The DC-resistance meter must be used with insulated pins to ensure that the readings obtained are always originating from between the tips of the pins. With this meter, the only boards that can be accessed are along the side of the kiln load. It is necessary to pin the boards from the edge, rather than the wide face as is typically done outside the kiln. The moisture gradient from the edge will be different from that on the wide face and this necessitates pinning a little deeper than normal. There is no rule on what depth to pin to, but if the normal pinning depth is 3/8-inch (9 mm) on the wide face it will be preferable to pin to about 3/4-inch (19 mm) from the edge. The most important consideration is to ensure that the pinning depth is kept constant. This can be done by placing a block over the pins to prevent them being driven in any deeper than the target depth. By keeping pinning depth and other test variables constant, more success will be obtained in correlating hot check results against other checks of final MC normally done at the planer mill.

When using a dielectric meter for a hot check, it must be fitted with a probe to insert between the sticker openings. As with the meter itself, the sensing pad at the end of the probe must make good contact with the wood being sampled.

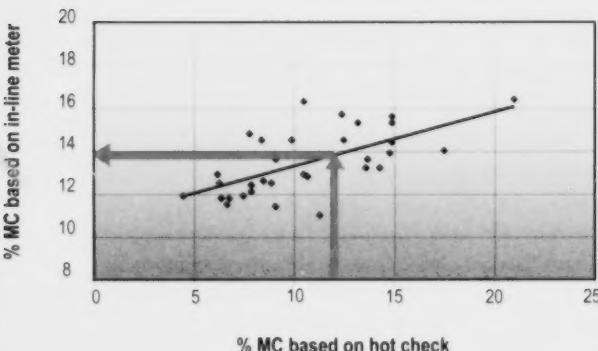
With both meters, correction factors must be applied either manually or automatically by the meter. For a DC-resistance meter it is necessary to correct for the effect of both wood species and temperature. In the case of temperature, it is often difficult to estimate the temperature of the wood itself. It is recommended to use a small gauge thermocouple wire and electronic thermometer to measure the internal temperature of the wood. The average of 2 or 3 readings should be sufficient, with the

caution that if measuring on both sides of the load the temperatures may differ. For the dielectric meter, species and temperature corrections are also required.

The most important aspect of a hot check is to standardize the sampling procedure and ensure that it is used consistently by each operator at a given mill. There are a large number of variables that can affect the relationship between the hot check and MC sampling taken later. Each mill therefore needs to establish its own correlation between hot checks and "true MC". Some of the techniques described in the section on in-kiln moisture sensors can be followed for developing a correlation between hot check results and the more accurate estimates of MC obtained later, after the lumber has cooled. Figure 14-3 shows a sample graph developed for a mill to correlate hot check results against final MC measured at an in-line meter in the planer mill.

Figure 14-3

Hot check moisture estimates should be calibrated against another system, such as an in-line moisture meter, to make the process more accurate and determine the most appropriate shut down time for the kiln.



Mill staff need to establish their own base line for final MC. This base line MC for any mill depends on the level of accuracy and expectations of customers. At an SPF mill producing dimension grade lumber it is important to compare hot check results against the same procedures used by the grading association to assess final MC.

A quick and easy measure of the effectiveness of a hot check is the number of times needed to re-start a kiln after conducting a hot check. One of the goals of conducting a hot check is to optimize the drying time for a particular kiln and product. If the lumber is always over-dried and it is never necessary to re-start the kiln this objective has been missed. Since drying times do

vary between loads of lumber, a successful hot check procedure will inevitably identify charges that need to be re-started from time to time. Over time an operator will learn to judge how much additional drying time is needed based on the results of the hot check. Once this is done, a second hot check may not be necessary. A final check outside the kiln will be sufficient.

DRYING SCHEDULES

15.1 OVERVIEW

This chapter provides background on the process for developing a drying schedule as well as examples of specific drying schedules. Material presented in earlier chapters should help the reader select the best solution for their particular situation. There are too many variables that need to be considered to allow listing a schedule to cover every possible industrial drying scenario. Schedules are listed for specific species and dimensions and guidance provided on how to select or modify a schedule for species mixtures. No claims or assurances are made with regard to drying time or quality. The schedules provided should be considered as starting points from which a mill can develop their own site-specific drying procedures.

Most of the Canadian lumber drying industry still operates with control systems and drying schedules based on temperature in degrees Fahrenheit. In order to simplify the presentation and interpretation of drying schedules in this chapter they will all be listed in Fahrenheit. A table of conversions is listed in Appendix I of this manual.

15.2 STRATEGY

Anyone who has operated a kiln drying SPF lumber will already know that there is no "cookie-cutter" approach to drying this species mix. A lot of attention has been given in earlier chapters to the diversity of material properties both within and among species. In addition there are many site-specific factors to be taken into consideration. Everything from logging practices to green lumber storage in the mill yard and the various steps in between can have an impact. As a result it would be impossible to provide specific drying schedules to cover every potential situation.

The objective of this chapter is to build on the knowledge gained from understanding the material and the drying process and to apply that knowledge to develop drying processes that work well for a particular situation. Hopefully, by the end of this chapter, the reader will be in a better position to use the examples provided and the

strategies described to develop their own specific drying process.

The term "drying process" is used instead of "drying schedules" to convey a specific message. "Drying process" is a broader term that encompasses not only what is done when the material is in the kiln, but many of the pre- and post-drying practices such as:

- whether a mill is pre-sorting
- whether a mill is air drying
- whether a mill is re-drying.

These are all examples of dynamic processes going on that must be understood, monitored, and, in each case controlled in order to maintain good productivity and highest recovery of upper grade products.

15.3 SETTING THE TARGET

The first step in any journey should be to know the end point. Setting good targets helps everyone focus on modifying the process to achieve the objective. Targets can always be modified later if it is found that the cost of achieving them is too high. Without them, however, many operators will end up searching for the right solution and may not even recognize it when it happens.

What are the targets that need to be set and how are they set? The key element at this stage is communication with and involvement of others within, and perhaps outside, the operation. One objective of any drying operation is to get the material to a condition that it will perform well in its intended end use. Therefore some knowledge of the end use of the material is necessary in order to set realistic goals and objectives for the drying operation. For a SPF operator there are a number of potential end and intermediate users of the product that will have an interest in the dry lumber quality. The following is a list of traits that are desirable from the standpoint of different stages in the lumber manufacturing and utilization chain.

- The planer mill operator likes flat lumber that is not too dry on the surface as this material will machine well and reduce the incidence of jam ups at the planer.
- The mill manager wants good straight lumber in order to get the highest percent of upper grade lumber that is dry enough that no claims are being made on final MC, and that is dried in the shortest time possible.
- The grade inspector wants to see that the lumber is dry enough to meet the 19% MC requirement.
- The end user wants straight lumber that will remain straight.
- The kiln operator wants to keep all of the above happy!

Fortunately, these desired attributes are not mutually exclusive but they do require that the kiln operator develops a compromise strategy that keeps everyone happy. The first part of that strategy is setting the targets for the drying operation. The following criteria can all be considered in setting up targets for the drying operation.

15.3.1 FINAL MOISTURE CONTENT

Final MC is the most obvious objective in drying. In North America, the National Lumber Grades Authority (NLGA) specifies that if lumber is to be marked as "S-Dry" it must be dried to a MC of 19% or less. Furthermore, if an inspection of final MC is conducted, 95% or more of the material must be at 19% MC or less. This is the requirement that most SPF operators have targeted over the years. However, this is a market requirement for final MC and should not necessarily be considered as the final MC target at the kilns. Circumstances may dictate that a different target is developed for the kilns in order to maximize productivity and/or grade recovery.

Recently, certain products or markets have started demanding MCs different than the traditional 19% value for SPF lumber. The NLGA specifies that material can be marked at a different final MC requirement such as "MC-15". This allows the supplier and user to agree on a different MC. In many instances, however, the final MC requirement may be set directly between the end user and supplier. In some cases this may be another manufacturing step such as a glulam or I-beam operation. In other cases it may be a special requirement developed by a wholesaler or retailer of the product. When wood is to be stored in and sold from a heated warehouse type of store (rather than the traditional lumber yard) it may be desirable to dry it to a lower MC. In other cases, the lumber manufacturer themselves may decide to develop a different specification as part of a marketing strategy. It is impossible to list specific target MCs for every situation. These targets need to be developed taking into

consideration the needs of the end user(s). Many traditional markets for SPF lumber will continue to request "under 19%" as the requirement but even this needs to be clearly defined. NLGA grading rules allow for up to 5% of the product to be off "spec" for final MC. In some cases, such as a RF gluing operation, even 5% of material above 19% MC may be enough to cause problems. As another example a glulam manufacturer may request that all material be dried to an average MC of 12% +/- 2% MC. In another case, the end user may be concerned about not only the average or maximum MC but may want to avoid too much over-dried material.

Thus it is important to discuss the needs of the end user and then clearly agree on the target. Once that is in place, the kiln operator can develop drying strategies that will achieve those targets. Once the targets are known, the kiln operator can also comment on the attainability of them given the known properties of the resource and capabilities of the equipment. For example, if a tight final MC requirement is needed and the resource mix has a high percentage of balsam fir, the kiln operator will need to run a relatively long, mild schedule with a long equalization treatment. The kiln operator and management can then make a judgment on whether or not this can be done economically.

15.3.2 DRYING DEGRADE

Defining an acceptable level of drying degrade is another objective that should be clearly stated from the outset. Drying degrade refers to the loss in value associated with drying.

As with moisture specification, the NLGA grading rules define what is allowable in terms of the various forms of warp. These are usually minimum standards to target and the market may demand something different. As an example, many companies selling "Premium" grade material will specify that warp levels be no more than half of that allowed in No. 1&2 Common lumber.

Another component of drying degrade is trim loss. Volume loss due to trimming to remove drying defects and the drop in grade described above will combine to create a certain value loss due to drying. It would be easy to specify that losses due to drying should be "zero" or "minimal" but it is more reasonable and realistic to set an achievable target against which the performance can be measured. Ways and means of measuring the value loss associated with drying are described in Chapter 18 "Quality Control Measures".

Setting a target and then measuring performance against it will help the kiln operator modify drying schedules. As

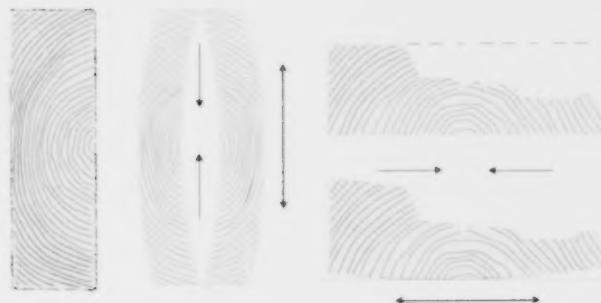
an example if the material being dried is warp-prone, the kiln operator may want to run a milder schedule to avoid over-drying too much material.

15.3.3 DRYING STRESS

In most applications for SPF lumber, drying stress is not a concern. Drying stress becomes a concern when the end user will be machining the wood into a shape different than the regular rectangular cross-sectional shape of dimension lumber. Another situation where stress is of concern is when the wood is to be re-sawn. Examples of both are shown in Figure 15-1.

Figure 15-1

Residual drying stress can cause warp to develop in dry lumber that is either resawn or machined.



The important aspect from the point of view of the person setting up the kiln schedule is whether or not drying

stress is of concern. If it is, then a conditioning treatment must be incorporated in the schedule and some allowance made in the estimate of drying time.

15.4 STRUCTURE OF A DRYING SCHEDULE

15.4.1 DRY-BULB AND WET-BULB TEMPERATURE PATTERNS

Drying schedules can be described in a tabular or graphic form. Historically, drying schedules were typically a series of steps and, therefore, a tabular format worked well. Most kiln controllers now make changes on a gradual basis. For this reason a graphic format is usually the best way to view and compare schedules. A tabular format is more often used when translating the schedule into something the control system can implement and all control systems tend to have their own particular format. Schedules presented in this chapter will all be listed in a graphic and tabular format as shown in Figure 15-2.

The schedule shown in Figure 15-2 follows the typical pattern of a softwood drying schedule. The dry-bulb temperature starts low and, after an initial, rapid heat up phase continues to gradually rise over the course of the drying period. The difference between the dry-bulb and wet-bulb temperatures (known as the wet-bulb depression) also increases over the course of the drying schedule. This increase in depression is associated with a decrease in RH and equilibrium moisture content (EMC). Most drying schedules follow this pattern. The reasons for this are explained in the earlier chapters on Wood

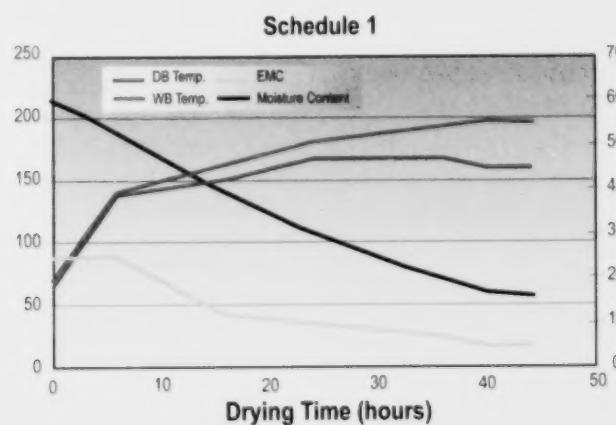


Figure 15-2

Typical pattern of an SPF drying schedule (Schedule No. 1 from Appendix IV).

Time (hrs)	6	16	24	36	42	End
Approx MC Range	Green-55	55-40	40-30	30-24	24-20	20-end
Dry-Bulb	140	170	180	190	195	195
Wet-Bulb	140	150	166	166	160	160
EMC	24.6	11.7	9.4	6.6	4.9	4.9

Structure as Related to Drying (Chapter 2), Wood Moisture Relations (Chapter 3), and Physical Elements of Drying (Chapter 6). Where schedules start to deviate from this pattern is when additional treatments to equalize or condition the wood are required.

15.4.2 AIRFLOW AS PART OF A DRYING SCHEDULE

Drying schedules, including those listed in this manual, do not typically include specifications for airflow. Dry-bulb and wet-bulb temperature affect drying rate of wood as does airflow (see Chapter 6). We know that higher airflow at certain stages in drying will result in an increase in drying rate. Therefore, it would make sense to include airflow as part of a drying schedule. It is only recently that kilns have started to be routinely equipped with adjustable speed drives, and without this equipment the implementation of a varying airflow rate would not be possible. For kilns that have this capacity, kiln operators should consider adding a column to their drying schedules to specify airflow. Since airflow capabilities vary widely from kiln to kiln it does not make sense to include them on schedules listed in this chapter but the following guidelines can be applied in setting airflow levels for schedule steps.

- At the start of the drying schedule, ramp airflow to the maximum level attainable for green lumber.
- Start to decrease airflow as the MC of the wood approaches the fibre saturation point (FSP).
- Consider using lower airflow for well air-dried material.
- Temperature drop across the load (TDAL) can be used as an indicator of airflow needs; higher TDAL = greater need for high airflow.
- Do not reduce fan speed to less than about 300 feet per minute airflow on the exiting side of the load.
- Refer to other material in this manual on airflow with regard to kiln maintenance and performance (Chapter 9) and effect of airflow on drying rate (Chapter 6).

There is no down side to too much airflow from a drying rate or drying quality standpoint. Assuming that the conditions of dry-bulb and wet-bulb temperature have been set at appropriate levels for the material being dried, airflow becomes just a means of achieving the desired drying rate uniformly across the load. However, there is an economic advantage to reducing airflow. Reducing fan speed reduces the electrical energy demand as well as the overall consumption. Even small reductions in airflow can have a significant impact on drying costs.

15.5 CONVENTIONAL VERSUS HIGH-TEMPERATURE DRYING SCHEDULES

The majority of kilns used to dry SPF lumber in Canada are classified as "conventional" in terms of their operating temperature capability. Although many of these kilns do surpass the boiling point for a portion of the drying schedule, they do not meet the typical criteria for high-temperature kilns. Therefore, most of the schedules presented in this chapter are designed for these kilns and involve maximum dry-bulb temperatures up to approximately 220°F.

High-temperature drying typically refers to equipment and schedules that operate for a majority of the drying time well above the boiling point of water. As described above, many schedules exceed the boiling for a small portion of the drying time, and in particular once the wood is near or below the FSP. A few examples of "true" high-temperature schedules are also presented in this chapter along with notes regarding their application.

15.6 DRYING SCHEDULES FOR 2-INCH DIMENSION LUMBER

As mentioned earlier, success in lumber drying depends on many variables and therefore it is always difficult to generalize the results even when the lumber is dried in similar kilns. Thus, published drying schedules should always be used as guidelines or 'starting points' that can be adapted or tailored to specific material characteristics or equipment capabilities.

One of the main challenges related to the drying of SPF lumber is related to the variation of initial MC. Variations in initial MC may be the result of natural variations among and within species or differences resulting from the manner in which the material has been handled and stored. Mills that employ 'green sorting' systems have alleviated the problem to a certain extent. However, most of these mills do not sort all lumber sizes so that the initial MC problem still persists for at least a portion of the production.

Kiln characteristics may also influence results from a drying schedule. As an example, published drying schedules assume that adequate air flow will be achieved through all portions of the kiln load. For many kilns, especially older kilns, that assumption may not be valid. Sticker variation and lumber package quality will influence air velocity and therefore expected drying results for a particular drying schedule may not be achieved because the kiln may not be capable of attaining and/or maintaining set points. Direct-fired kilns may not be capable of

achieving wet-bulb set points without supplementary humidification. In such cases, drying schedules may need to be adjusted to avoid drying degrade.

Drying SPF has changed significantly in recent years. Previously SPF was dried together as a single group at each mill regardless of the range of species present. By doing so mills invariably had to deal with over-drying the spruce and pine and under-drying the fir. The presence of excessive amounts of drying degrade and "wets" (boards in excess of maximum allowable MC) have convinced many mills to separate spruce and pine from fir for drying purposes. An immediate benefit was identified with a reduction in over-drying of spruce and pine. Subalpine and balsam fir require longer drying times and many mills report that best results are obtained when the species is air dried for a couple of months before kiln drying.

Table 15-1 provides the regular schedule number for each species along with alternate schedules. These numbers refer to the schedules for 2-inch lumber listed in Appendix IV. As each mill's drying demands and priorities will differ, three versions of each schedule are listed. Along with the regular or base schedule there are also "accelerated" and "conservative" versions of each. "Accelerated" refers to more aggressive drying schedules that should achieve a relatively short drying time but will not achieve the same level of final MC uniformity. "Conservative" schedules are those that are designed to handle difficult to dry individual species or groupings of species with a wide range of drying characteristics. The base schedules are suggested as a starting point. From there the results should be analyzed to determine if there is potential to benefit from applying the more conservative or accelerated version.

Table 15-1
Suggested regular, accelerated, conservative and high-temperature drying schedules for 2-inch SPF lumber. Schedules are listed in Appendix IV.

Species	Suggested Schedule(s) ¹			
	Regular Schedule No.	Conservative	Accelerated	High Temp. ²
Eastern white and red spruce	1	1-C	1-A	H-1, H-2 ³
Western white spruce and Engelmann spruce	2	2-C	2-A	H-1, H-2 ⁴
Black Spruce (yellow spruce ⁵)	3	3-C	3-A	Not recommended
Jack pine	4	4-C	4-A	H-1, H-2 ⁴ , H-3
Lodgepole pine	5	5-C	5-A	Not recommended
Balsam and Subalpine fir	6	6-C	6-A	Not recommended

Notes:

¹ See notes on selection and application of drying schedules earlier in this section.

² See notes on high-temperature drying in Chapter 6 and section 15.5.

³ Yellow spruce has a higher initial MC and dries more slowly than normal black spruce and should be dried on a conservative schedule.

⁴ For material starting at a low MC i.e., air-dried or insect-killed material.

15.7 SELECTING AND MODIFYING A DRYING SCHEDULE

There are many reasons why a drying schedule will not produce acceptable results for a particular situation. As described previously the variables introduced by raw material characteristics and equipment operating capabilities are too numerous to make it possible to develop schedules to cover every situation. Therefore it is quite likely that kiln operators will need to select a modified schedule or make modifications to suit their particular situation. The drying schedules for 2-inch dimension lumber presented earlier included accelerated and conservative versions of each schedule. This section will provide some further background on factors that may affect the selection of a drying schedule.

15.7.1 SELECTING A SCHEDULE FOR MIXED SPECIES

The schedules listed earlier in Table 15-1 for 2-inch thick dimension lumber are identified by individual species. In most cases, SPF mills are drying a mix of species from the SPF grouping. Drying characteristics can vary substantially within the individual species of the SPF grouping as described in Chapters 2 and 3. As a result, drying of mixed species will usually result in a compromise situation. The compromises are usually one of the following:

- Do you follow the drying schedule for the faster drying species and experience some "wets" in the slower drying species?
- Do you follow the drying schedule for the slower drying species and experience more over-dried material in the faster drying species?

- Do you modify the end of the drying schedule to equalize the material to avoid either of the above scenarios but at the cost of extending the drying time?

Inevitably the choice must be made for each drying facility based on site-specific information. Which option can be tolerated from the standpoint of productivity and mill profitability?

The question of which compromise to accept is easier when the differences among species are less extreme. Mixing pine and spruce in most regions is a better compromise than mixing balsam or subalpine fir with other species. Therefore, many mills look for options to handle the fir species separately and deal with drying spruce and pine together. For optimal performance at the kilns, however, even separating spruce and pine (as well as looking for other pre-sorting options) will produce the best results.

Anything that can be done to minimize the variability in the material in the kiln will make it easier to select, build or modify a drying schedule.

One way of producing a "blended" schedule for a species mix is to take the individual schedules for each species and compare them side-by-side. An example of how to do this is presented in Table 15-2. At each schedule step the lowest dry-bulb temperature, the lowest wet-bulb depression, and the latest time for the change in the schedule condition is selected. This will normally result in a schedule which is more conservative than either of the original schedules. This will help reduce the tendency to over-dry material. When drying any mix of species, however, it is important to increase the sample size when conducting hot checks in order to get a good measure of the final MC variability.

15.7.2 MODIFYING A SCHEDULE FOR 1-INCH LUMBER

Most softwood dimension mills produce a relatively small

proportion of nominal 1-inch thick lumber. In some cases this material is sold green for various applications where dry lumber is not essential. In other cases, this material must be dried and/or heat treated based on customer demands or market access issues. Since the volume of 1-inch thick material is usually quite small, mills are not always set up to handle this material effectively.

Some mills will pile their 1-inch lumber back-to-back with stickers between every second row and then dry the material as if it were 2-inch lumber (sometimes in the same kiln charge as 2-inch thick lumber). This practice can be effective for achieving heat treatment but is not conducive to achieving a well-dried product. Two 1-inch boards dried back-to-back will dry faster than 2-inch thick lumber. If dried together the 1-inch material will be over-dried. If dried on its own the back-to-back boards will develop a non-normal moisture distribution with the inside face of the boards having a slightly higher MC than the exposed face. There is then potential for this material to distort, usually in the form of cupping, after it is removed from the kiln and equalizes in storage or service.

If a well dried product is required, the best solution for 1-inch thick lumber is to place stickers between every row and dry the material on specialized schedules. The schedules for 2-inch lumber could be used to dry 1-inch material but the material will dry much faster and will likely have reached the target MC long before the last schedule step is reached. Therefore, the best solution is to reduce the length of time at each schedule step. The specific procedure for modifying a 2-inch schedule for 1-inch material would be as follows:

- Following the guidelines for schedule selection listed in the previous section, select a regular 2-inch schedule for the appropriate species.
- Follow the initial warm-up step without reducing the time.

Table 15-2

Example of how to produce a "blended" schedule from two individual schedules. At each schedule step select the least severe conditions (highlighted values) of dry-bulb temperature, wet-bulb depression, and schedule step time.

Schedule No. 2 ¹				Schedule No. 5 ¹				Blended Schedule			
Time (hrs)	DB (°F)	WBD (°F)	WB (°F)	Time (hrs)	DB (°F)	WBD (°F)	WB (°F)	Time (hrs)	DB (°F)	WBD (°F)	WB (°F)
6	140	0	140	6	140	0	140	6	140	0	140
16	160	5	155	16	165	5	160	16	160	5	155
24	180	8	172	24	185	8	177	24	180	8	172
36	190	16	174	36	195	16	179	36	190	16	174
48	195	27	168	42	200	26	174	48	195	26	169

¹ Schedules taken from Appendix IV

- Reduce the time at each subsequent schedule step by approximately 50%.
- Until a target drying time has been established start conducting hot checks at approximately 40% of the time normally required for 2-inch lumber.

Drying times for 1-inch lumber in any species are typically somewhat less than half of the time required for 2-inch material. A general rule of thumb used for hardwood lumber is that doubling the thickness will result in approximately a tripling of the drying time. The same reduction in drying time for thin lumber is not usually achieved in softwood dimension lumber drying for several reasons. Drying schedules for softwood dimension lumber are not constrained by the same internal drying stress limits as dense hardwoods. A large proportion of 1-inch lumber originates from the outer portion of the log and therefore contains a large proportion of sapwood. In most softwood species, the initial MC of sapwood is at least twice as high as that of heartwood. As a result, drying times for 1-inch softwood are more likely to be in the order of 50% of the time required for 2-inch material. Until a target drying time has been established it is recommended that an initial hot check be conducted at approximately 40% of the time required for 2-inch material of the same species or species mixture.

Air drying will reduce kiln residence time. For the same reasons listed above, 1-inch lumber will air dry quite rapidly. Therefore, if material is stored outdoors for any significant period of time, the rules on drying time in the kiln will be altered. In such cases, the kiln operator will need to be more vigilant and monitor the kiln drying phase more closely.

An important consideration when drying 1-inch, or similar thickness material is the piling. Proper piling techniques are described in Chapter 12. A sticker spacing of no more than 24 inches is recommended for 1-inch thick lumber. Since this material is thinner, and therefore weaker, proper sticker and bunk alignment are critical to maintain straight lumber.

15.7.3 MODIFYING A SCHEDULE FOR THICK LUMBER

A relatively small volume of SPF is sawn into material thicker than 2 inches. In most cases, this material is being produced for special orders rather than as a commodity product for the open market. As a result, it is usually the end use that will define the final MC requirement and other aspects of dry lumber quality. This could include tolerance of or limits on MC gradients, drying stresses, warp, surface checking and discoloration. It is important to have access to and take into consideration

all of these product quality criteria before making any decisions on how to dry the lumber.

The following schedule developed for 3- and 4-inch thick softwood lumber is relatively conservative. The drying times are approximate and, until a target drying time has been established, frequent hot checks should be conducted to determine the appropriate end point. The schedule, as listed, is suggested for spruce and pine lumber. Balsam and subalpine fir can be dried on this schedule but the time at each schedule step should be increased significantly.

Table 15-3

Drying schedule for 3- to 4-inch thick spruce and pine lumber.

Step Duration (hrs)	Dry-Bulb (°F)	Wet-Bulb (°F)	EMC
12	130	125	16.0
24	135	130	15.9
48	140	135	15.8
48	145	135	11.9
48	150	135	9.5
48	155	135	8.0
48	160	135	6.8
48	175	135	4.4
Total 324 hrs			

In cases where a more severe drying schedule can be tolerated, the conservative version of the appropriate 2-inch drying schedule presented earlier in this chapter can be modified for 3- and 4-inch material. As a guideline, the 2-inch schedules can be modified by doubling and tripling respectively the duration at each schedule step for 3- and 4-inch thick material. Again, frequent hot checks (or other means of determining the in-kiln MC) should be implemented to identify the most appropriate end point.

A similar process (increasing time at each schedule step) can be applied to material thicker than 4 inches. In most instances however, material over 4 inches thick is seldom required to be dried to a low MC throughout the cross section. Typically, this material is either put in the kiln to dry only the outer shell to avoid mould and sap-stain growth or is air dried first and then placed in the kiln to achieve heat treatment. Further detail on heat treating material is presented in Chapter 19.

15.7.4 MODIFYING A SCHEDULE'S DRYING SEVERITY

The drying schedules presented in section 15.5 for 2-inch dimension lumber include both accelerated and conservative versions of each schedule. These schedules have been

modified following some straightforward principles that can be applied to any drying schedule. These principles are summarized here as guidelines for those who wish to further modify these or any other drying schedules.

In order to evaluate the effectiveness of any change in an operation requires that information is gathered on the overall performance of the system. In drying this would ideally mean having the ability to monitor the properties of the material both as it goes into as well as out of the kiln. This information is important for a good quality control system. Information gathering and analysis as part of a quality control program is covered in detail in Chapter 18.

The results of a thorough inspection of dry lumber will indicate whether or not a more severe or conservative drying schedule would help achieve the objectives set for the kiln (see section 15.3 "Setting the Target").

Drying schedule severity is the result of a number of factors. For most drying operations the three main variables that can be adjusted are dry-bulb temperature, wet-bulb depression and time of schedule change. The general trends with regard to each of these on drying schedule severity are listed in Table 15-4. More specific information on the impact of these variables on drying is presented in Chapter 3 (Wood Moisture Relations) and Chapter 6 (Physical Elements of Drying).

Table 15-4

Modifying the kiln operating parameters to produce an accelerated or conservative version of a drying schedule.

Schedule Parameter	More Severe (Accelerated)	Conservative
Wet-bulb depression	Increase depression	Decrease depression
Dry-bulb temperature	Increase temperature	Decrease temperature
Schedule step changes	Shorten (make schedule change sooner)	Lengthen (delay making schedule changes)

Patience is the order of the day when it comes to making schedule changes. Changes to schedules should be made in small incremental steps and time given for the effect of those changes to show up in the final product.

Avoid making quick decisions on the effectiveness of a schedule change based on the results of just one charge of lumber. The outcome of a single charge may be influenced by many variables other than schedule. Also avoid changing too many variables at once. For example if you are trying to improve final MC uniformity by developing a more conservative schedule you may want to start with a reduction in wet-bulb depression toward the end of the schedule. If it is found that the new lower depression cannot be achieved it may then be necessary to also lower the dry-bulb temperature. Finally, it is important to document the type of changes that were made, when they were made, and take note of any non-normal conditions that may develop during the transition period that may also affect the outcome.

15.8 IMPACT OF PRE-SORTING ON SCHEDULE SELECTION

The reasons for pre-sorting and the methods used are described in Chapter 11. Pre-sorting results in groups of wood that inherently have different drying properties. Each group will have different drying times even if dried on the same schedule. Further benefits from pre-sorting can be realized by developing drying schedules specific to each group of material. The schedules listed in the previous sections are for individual species but also include both accelerated and conservative versions of those schedules. This section provides some advice on the application of these schedules for lumber that has been pre-sorted.

Table 15-5 provides descriptions of various wood groups as sorted prior to drying. Included in the Table is a recommendation with regard to the type of schedule to apply. For example if you are dealing with black spruce and sorting based on density, a more conservative schedule is suggested for the high density material. A conservative schedule for black spruce could then be selected from those listed in Table 15-1 or the current schedule modified as described in the previous section.

15.9 IMPACT OF FROZEN LUMBER ON KILN OPERATION

Wood containing free water is a relatively good thermal conductor. Whether or not the wood is frozen, if sufficient heat is applied at the surface it will only take a relatively short period of time to get the core heated to something close to the operating temperature of the kiln. This is reflected in the heat treatment schedules listed in Chapter 19 but was also demonstrated in a Forintek study on effect of frozen lumber on drying operations. That study concluded that the limiting factor in

Table 15-5

Recommended drying schedule severity (regular vs. accelerated vs. conservative) based on pre-sorting criteria.

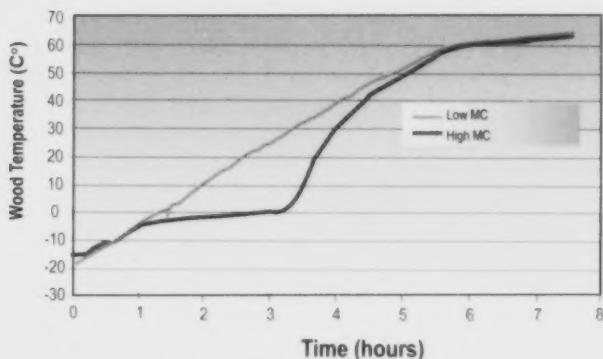
Sorting Criteria	Sorted Description	Schedule Severity Recommendation			
		R=Regular, A=Accelerated, C=Conservative			
Initial MC	High	R	C	R	C
	Middle	A	R	A	R
	Low	A	R	A	R
Specific Gravity	High	C	C	R	C
	Middle	R	C	A	R
	Low	A	R	A	R
Bulk Specific Gravity	High	C	C	R	C
	Middle	R	C	A	C
	Low	A	R	A	R

heating a load of frozen lumber is not the heat transfer properties of the wood but is more related to the heating capacity of the kiln itself.

Figure 15-3 shows how the core temperature of a piece of frozen, green, 2-inch lumber changes as it is heated. There is a plateau in the temperature curve around the freezing point (0°C) associated with the phase change from ice to liquid water. The extra energy required to make this phase change is referred to as the heat of fusion. The heat of fusion from ice to liquid water is 334 Kilo-joules per kilogram (144 btu/lb).

Figure 15-3

Heating rate in a small laboratory kiln for frozen, 2-inch thick (nominal) lumber comparing one piece starting a low initial MC versus another at a high initial MC.



A large kiln load of frozen lumber with a high initial MC will therefore require a significant amount of energy to raise the temperature. If the kiln is not able to rapidly supply that energy the heating of the load will be delayed. If the kiln is able to supply the required energy, wood can be thawed and heated to the operating temperature in a relatively short period of time as shown in Figure 15-3. As shown in this figure, the low and high initial MC boards achieve the same core temperature at approximately 5 hours.

Another factor that is often overlooked with frozen lumber is the starting MC. Many operators attribute the longer heating and overall drying times to the fact that the wood was frozen. In addition to the extra energy demands noted above, there is also the distinct possibility that the wood will be starting at a higher initial MC during the winter. This is usually a consequence of the poor air drying conditions that exist during the winter months. Lumber sitting in the mill yard for several weeks during the winter will not dry anywhere near as much as it will in the summer. Data on air drying rates are presented in Chapter 13 on Air Drying. This higher initial MC will not only result in a longer drying time but will also increase the energy demands on the system. Again, if the system is limited in this capacity, the drying times will be extended due to a slower heat up rate.

The above factors should be taken into account when applying a kiln schedule. If the kiln is able to achieve it, a rapid heat up rate on frozen lumber will help achieve shorter drying times without detriment to the lumber.

However, drying times may need to be extended to account for the higher initial MC of the lumber during the winter months.

Well air-dried wood will typically be close to or below the FSP and, as a result will not be affected by the above. Since there is no free water present, there will be no phase change and therefore no significantly higher demand on the heating system. Air-dried lumber can be heated rapidly regardless of its starting temperature.

It should be kept in mind, however, that if the kiln is poorly insulated and has considerable leakage that the heating times during the winter will be extended regardless of the starting MC of the lumber.

15.10 ENTERING VERSUS EXITING AIR SCHEDULES

The concept of temperature drop across the load (TDAL) is described in Chapter 6. TDAL inherently results in a lower dry-bulb temperature on the exiting side of the lumber stack. If this exiting dry-bulb temperature is used as the control temperature of the kiln, the drying schedules need to be designed accordingly. This principle of operation is a feature of some automated control systems. It provides a way of responding to the drying load by supplying more heat (higher temperature) on the entering side of the load when the drying load is high. Temperature drop across the load (TDAL) is an indicator of the progress of drying; when TDAL is high the wood is drying rapidly and when it is low drying rates are slow.

If drying conditions are set based on the exiting air temperature, then the entering air temperature becomes a result of the TDAL. The schedules presented in the previous sections are all based on entering air conditions. To apply these schedules with a controller operating on ex-

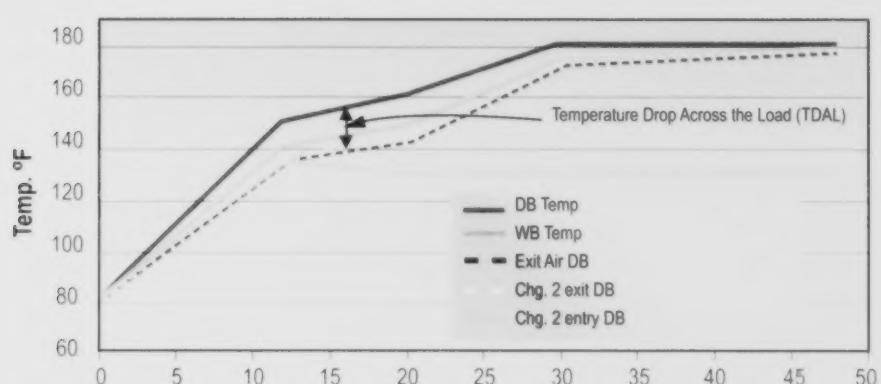
iting air will require some knowledge of the TDAL values that typically develop at various stages of drying. TDAL is affected by factors other than just the MC of the wood such as airflow, stack width, piling pattern, and other site-specific characteristics. Therefore it is not possible to give a straightforward conversion procedure to modify an entering air schedule to an exiting air schedule. If the operator knows, or can collect some data on TDAL for a particular kiln, that information can then be used to transform a schedule.

Figure 15-4 shows the entering and exiting dry-bulb temperature for a typical drying run. The typical pattern of TDAL results in less difference between the entering and exiting dry-bulb temperature toward the end of the drying schedule. Therefore the difference between an entering and exiting air schedule will be greater at the start of the drying cycle than toward the end.

Some operators prefer to run with exiting air schedules as they can compensate for variations in charge conditions from load to load. An example is shown in Figure 15-4 for two different kiln loads from the same kiln. Charge No. 2 had a higher initial MC and therefore created a greater TDAL. Even though the exiting air condition is similar for both loads, the entering air temperature is different. As a consequence, the wetter load is dried on a harsher schedule, based on the entering air conditions. In this manner, the exiting air control strategy compensates for wetter versus drier material. This strategy works well as long as the conditions created do not cause other problems. Operators need to be aware of the conditions in all regions of their kiln when setting up a drying schedule. What may appear to be a conservative schedule based on exiting air may in fact be quite severe. This same caution applies when comparing schedules.

Figure 15-4

Diagram of two kiln loads operating with a similar exiting air temperature but different entering air temperatures due to MC differences between the material



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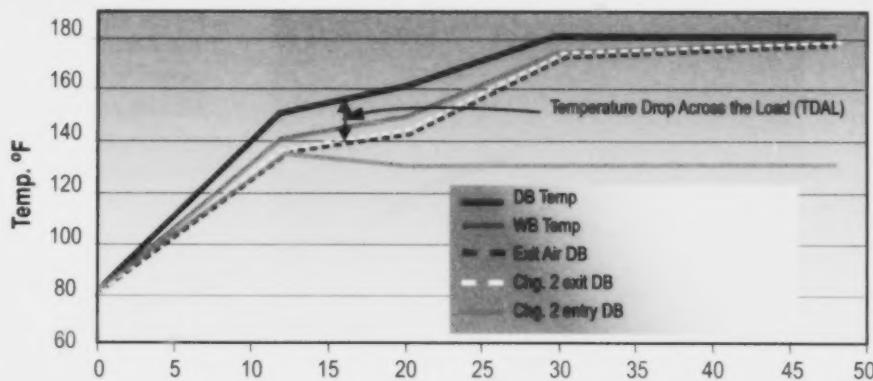
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Figure 15-4

Diagram of two kiln loads operating with a similar exiting air temperature but different entering air temperatures due to MC differences between the material.



15.11 NOTES ON DRYING TIMES

Drying times listed in the schedules presented in this manual are strictly estimates. Actual drying times will vary depending on many factors such as resource characteristics, green log and lumber handling and storage practices, and drying equipment condition and capabilities. As many of these factors will vary from site to site it is usually difficult to compare drying times between sites.

Drying time should not be the only or, in many cases, even the main criteria for judging a drying schedule's effectiveness. Productivity is always a major concern for producers of any product but especially commodity products. However, lumber quality issues may over-ride drying time considerations even in a commodity product setting. When it comes to drying schedule modification, improved quality usually implies extra time in the kiln. Therefore the only way to justify the extra time in the kiln is to measure the product quality. Ways and means of doing this are described in Chapter 18 (Quality Control).

NOTES

STORAGE AND SHIPPING OF DRY LUMBER

16.1 INTRODUCTION

Moisture content (MC) specifications that are laid down for dried lumber are based on the ultimate end use of that lumber. It is usually assumed that it is largely the responsibility of the kiln operator to have the lumber at that MC. However, once it has left the kilns, the storage and transit conditions can play a large part in determining the actual MC that exists when it reaches the customer. Lumber that has been kiln dried to a particular MC can lose further moisture if it is placed in an environment with a substantially lower equilibrium moisture content (EMC), or likewise it can gain moisture if exposed to a higher EMC.

16.2 STORING DRY LUMBER ON STICKERS

Most of the material in this chapter relates to the transportation and storage of dry-dressed lumber. The storage period of dry rough lumber between the kilns and planer mill must also be addressed when setting up procedures to maintain the final MC of the lumber. In most situations involving construction grade lumber, a short exposure period outside will not harm the material. In fact, a few days of outdoor exposure is often desirable as it helps raise the surface MC of the lumber and improves its machinability. Even a small amount of rain is not detrimental as the moisture absorption is primarily on the surface and this material will be machined off at the planer mill.

Problems arise when the wood is exposed to extreme or prolonged conditions of rain or snow that subsequently melts. In such instances, there is the potential that the average MC of the material will be raised above the target. Even if the moisture that is re-absorbed does not penetrate to the core of the material, it may well be enough to raise the average MC to an unacceptable level. Hand-held and in-line meters are influenced by surface moisture and will therefore detect this material as "wet" even if it is not significantly beyond the target MC.

The most practical protection for rough dry lumber stored on stickers is to manage the storage period to achieve the benefits and, at the same time, avoid the problems described above. This "safe" storage period will vary considerably depending on the geographic location of the mill and the time of year. The only way to establish this safe storage period is to conduct extensive checks of final MC both immediately following the kiln and immediately prior to planing. In this manner, operating guidelines can be established. However, any time wood is left exposed to the environment, there is always the potential for problems.

The above procedures will work well for relatively short-term storage of rough dry lumber that has been dried to 19% and less. When storage times are longer or when dealing with material dried to lower MCs, other means of protection may be required. The best protection for rough dry lumber is under cover. Mills in areas that experience a lot of rainfall will often install a covered area at the outfeed of the kilns. This allows the material to cool and "equalize" somewhat before being planed. An open-sided, covered building will usually provide sufficient protection for SPF lumber.

16.3 EFFECT OF RAIN AND SNOW ON DRY LUMBER

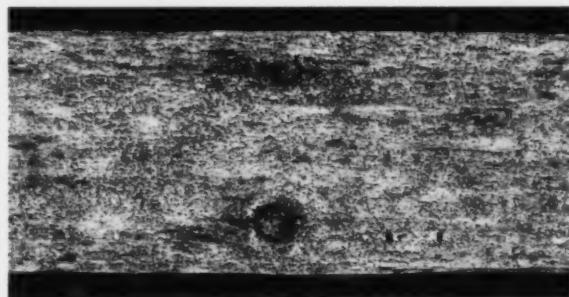
Dry lumber may be rained on, both while it is being transported and while it is in storage. Moisture is absorbed readily and the surface MC quickly rises in rain. Repeated wetting and drying of the surfaces gives lumber a very weathered appearance, and the swelling or shrinking that accompanies the changes in MC causes surface and end checks.

As an example, rain and snow falling on unwrapped, packaged lumber (or packaged lumber with a torn wrap), at a construction site wets not only the exposed surfaces, but also seeps down between the rows of boards. While exposed surfaces dry readily moisture will be retained in-

side packages. Problems can arise if this packaged lumber is stored for lengthy periods of time before being used. Water trapped inside the package can raise the MC of the wood to a level high enough to permit fungal growth—generally considered to be 22% MC or higher. At best this is unsightly when the wood becomes discolored from surface moulds and blue-staining fungi. At the worst, wood left in this condition for an extended period of time may develop rot and the lumber would be unusable.

Figure 16-1

Dry lumber that has been allowed to regain moisture can quickly develop surface mould, especially if left in a solid-stacked condition.



16.4 EFFECT OF STORING DRY LUMBER WITH WET LUMBER

Kiln-dried lumber can, under certain conditions, gain moisture when it is shipped or stored with green lumber. There are various reasons why moisture regain may happen. Direct contact with green lumber in the same hold or storage area will allow moisture to migrate from the wetter wood. If shipping by container or other closed space, high EMC conditions may develop in the closed air space and this could cause re-wetting of the wood directly or via condensation produced in the container.

Any dry lumber that is placed in direct contact with lumber at a much higher MC will gain moisture. In packaged lumber, only the outside boards will make contact and, while their gain in MC may be large, there will be very little effect on the average MC of the package. Nevertheless, since the outside boards can become wet enough to develop mould and stain, care should be taken to prevent contact between dry and wet lumber.

EMC levels in a ship's hold will normally rise during a voyage due to evaporation from green lumber to the air and, in some areas, due to the entry of high EMC outside air. The practicalities of loading and unloading ships usually make it impossible to segregate wet and dry lumber into separate holds. Therefore there

is always a large volume of water in the green lumber capable of evaporating into the air and, consequently, the relative humidity (RH) in a closed hold is very high. Ventilation and de-humidification will help to keep the level down. The following example (Table 16-1), taken from past research, shows the effect of storage conditions on the MC of dried lumber. The data refer to a shipment of 2-inch spruce from Vancouver to Australia.

Table 16-1

Effect on MC from shipping lumber by boat for 66 days in a closed hold.

Average Moisture Content		When Loaded	When Unloaded	Maximum MC of any Board
Stored with dry lumber	18.7%		- 0.3%	19%
Stored with green lumber	19.1%		+ 3.2%	26%

A particular problem of condensation arises in holds due to incoming warm humid air being cooled to below its dew point when it hits cold lumber or cold steel frames. The condensation so produced collects or drips onto the dry lumber packages and the high MCs thereby produced allow fungal growth to proceed.

16.5 EFFECT OF STORAGE OUTDOORS OR IN OPEN SHEDS

Lumber stored open to the air, but sheltered from rain and snow, will change MC according to the prevailing EMC conditions. The more exposure that the lumber has to the air, the faster will be any change in MC. Solid-stacked lumber has limited exposure to the air and will therefore change in MC more slowly. However, if dried lumber is left in a stickered pile, all pieces will tend to change in MC as the EMC changes. Table 16-2 provides a listing of outside average EMC conditions for a sample of Canadian and U.S. cities. This table clearly shows situations where moisture regain may be an issue for low MC dried material and where continued moisture loss may be an issue for other material.

Moisture pick-up or loss by dried lumber is affected by the conditions that were used to dry the lumber. In general, air-dried lumber shows a greater gain in MC for a given time than kiln-dried lumber. Lumber that is kiln-dried at high temperatures i.e., over 100 C (212 F) will gain less moisture than lumber dried at lower or conventional temperatures.

Kiln-dried dimension lumber that is dried to below the 19% MC limit is extremely unlikely to regain sufficient moisture from high EMC air to raise its MC over the limit; therefore, it can be stored satisfactorily in an open shed. Shop grade and finish lumber that is dried to lower MCs, for example, 9% with a range of 7 to 11%, should not be stored in an open shed. In one test, western spruce that was kiln dried to 7% MC and stored in an open shed in Vancouver, rose to 14% MC after 46 days. Similar material was also stored in a closed shed heated to a temperature of 15°C (59°F) during winter months, and over an 11-month period rose in MC from 6.3% to 10.9%. It can be concluded therefore that shop grade and finish lumber shows a much slower MC gain in a closed and heated shed.

Table 16-2
Outside, average EMC conditions for various North American locations.

City	Average Outside EMC Condition			
	January	April	July	October
Halifax	14.6	13.6	13.8	16.1
Montreal	13.8	11.5	12.6	13.8
Toronto	15.7	12.4	12.3	14.6
Winnipeg	16.6	11.2	12.9	13.0
Calgary	10.8	9.5	10.4	9.9
Vancouver	17.6	14.7	13.8	18.0
Atlanta	13.3	11.8	13.8	13.0
New York	12.2	11.0	11.8	12.3
Chicago	14.2	12.5	12.8	12.9
Phoenix	9.4	6.1	6.2	7.0
Los Angeles	12.2	13.8	15.0	13.8

From: U.S. Dept. of Agriculture, Forest Service Research Note FPL-RN-0268 "Equilibrium Moisture Content of Wood in Outdoor Locations in the United States and Worldwide".

Figure 16-2
Dry lumber stored at a building site can quickly regain moisture if left uncovered or in contact with the soil.



16.6 DRY LUMBER STORAGE IN CLOSED HEATED BUILDINGS

Problems can arise in winter in closed heated buildings, such as woodworking plants, when lumber that has been carefully dried to a particular MC is then subjected to considerably lower EMC conditions. In winter, the outside cold air, which can hold very little moisture, enters the plant by forced or natural ventilation and is then heated to room temperature. Its RH and EMC fall sharply and the wood dries further. Warping or checking can result and the wood can become difficult to process and unsatisfactory to use. The following table illustrates the changes that can develop when outside air, at 75% RH and various temperatures, is heated to 22°C (72°F).

Table 16-3
Effect of raising dry-bulb temperature on RH and EMC.

Outside Air	Resulting Inside Conditions When Heated to 22°C (72°F)			
	Temperature (°C) (°F)	Relative Humidity	New RH (%)	EMC (%)
10 50	75%	34.4	6.7	
5 41	75%	24.3	5.1	
0 32	75%	17.0	3.9	
-5 23	75%	11.5	2.8	
-10 14	75%	7.3	1.9	
-15 5	75%	4.6	1.1	
-20 -4	75%	2.9	Less than 1.1	

To overcome this problem, it is clear that humidity must be added to the air and that the level of humidity in the air be controlled. In this way, the EMC and the wood moisture MC can be kept at a near constant level. Automatic humidification equipment to fulfill this function should be installed. Some of the humidification technologies discussed in Chapter 8 for kilns can also be used to humidify storage or manufacturing areas. This would include low pressure steam sprays and water atomizing systems.

16.7 PROTECTION OF DRY LUMBER DURING SHIPPING

16.7.1 CLOSED CONTAINERS

The ideal solution is to transport dry lumber in closed box cars, trucks or containers and store it under cover in sheds or closed buildings to protect it from rain and snow. Lumber dried to low MCs for furniture, millwork or joinery stock is often shipped in closed containers to provide the best protection against moisture regain.

These measures are not always practical or possible and alternate methods must often be used.

16.7.2 PROTECTIVE WRAPS

Dry lumber transported on railway flat cars or flat bed trucks is usually wrapped in plastic or waterproof paper. These covers are very effective provided that they are not damaged by poor handling or by wind. The cover will usually remain with the lumber up to the end user where it can then serve as protection for full or opened packages of lumber at building sites.

Most lumber wraps used today are composed of a woven plastic fabric (polyethylene and/or polypropylene) with company colours on the outside and a black layer to the inside. A lighter colour on the outside will reduce the heating effect and thereby minimize evaporation under the wrap. The black layer helps protect against ultra violet (UV) penetration, minimizes any weathering effect on the wood and reduces the risk of condensation. There are also wraps composed of a plastic outer layer with a paper inner layer. The paper reportedly provides some wicking properties to direct moisture away from the wood's surface. From a wood drying standpoint, the important characteristic of a lumber wrap is its water resistance. There are a number of other factors which need to be taken into account when selecting a wrap including longevity, tear resistance, recyclability and cost. As long as they do not become damaged all commercial wraps provide a waterproof barrier and are an effective way of maintaining MC in construction grade lumber.

For material dried to lower MCs, solid stacking and wrapping will provide protection against moisture regain but will not prevent the inevitable. If the surrounding EMC is higher than the MC of the wood, the wood's MC will rise. A lumber wrap will slow down the process of moisture regain and as long as storage and shipment times are kept to a minimum, this can be an effective way of shipping low MC material.

Although wrapping provides good protection, some precautions need to be taken when using it. Wrapped lumber may, in some circumstances, actually promote the build-up of moisture on lumber surfaces. SPF lumber that has been kiln-dried to a uniform MC of 19% and lower contains between 3 and 4 pounds of water per cubic foot of wood. This water, in the form of bound water and water vapour, can move within the wood in response to changes in temperature. If the surface temperature of the wood falls, the vapour pressure at the surface falls, and moisture moves from the inside to-

wards the surface and can evaporate from the surface. If the surface temperatures rise, then the vapour pressure at the surfaces rises and moisture will move towards the center of the boards.

If moisture evaporating from the surface is contained within the wrapping material, then in time it may condense and accumulate on the wood surface. The wood surface can then be wetted sufficiently to support fungal growth. The problem can become particularly serious if the package contains lumber that has pockets of moisture considerably higher than 19%. Wet pockets remaining in dry wood in species such as balsam fir and subalpine fir can contribute to this problem.

To reduce the problem of moisture build-up inside wrappers most wrapping is done on only the four sides and top surface of the bundle. Leaving the wrapper open at the bottom allows some escape of moisture. Colours on wrappers have been modified to reduce the radiant heating effect when packages are placed out in the sun. Some sectors of the wood industry, especially mills producing value-added products, have opted for a shrink wrap type of protection. These work well on low MC material that is not going to be stored outdoors for long periods of time. The problem with leaving such a wrap outside is that it acts as a greenhouse where the wood inside is heated, dries a little, and the water vapour ends up condensing on the inside of the wrap.

An alternative to wrapping is treatment with a water-repellent chemical. There are a number of these products available, and they are typically applied by spraying individual boards. These treatments have been used in the past, especially on coastal lumber products being exported overseas. Most companies, however, now opt for the physical barrier and protection provided by a lumber wrap.

16.7.3 SHIPPING ON OPEN TRUCKS

Unwrapped dry lumber is sometimes shipped on open flat-bed trucks. Depending on the time of year and weather conditions this material will be susceptible to moisture regain. If being shipped short distances in good weather this is an acceptable means of transportation. For longer distances or when there is inclement weather, the lumber should either be wrapped, as described above, or a tarpaulin used to cover the entire load. A tarpaulin will provide protection during transit but the wood will still be exposed during the loading and unloading operations until it can be placed under cover.

16.8 PROTECTION OF DRY LUMBER AFTER SHIPPING

Moisture content in wood is a dynamic property continuously changing as the environment that the wood is exposed to changes. This process does not end once the product arrives at the customer's site. Wood can often sit for periods of time at construction yards, wholesaler storage yards and retail stores. When problems concerning MC arise at any of these stages in the lumber handling process the first suspicion is that the material was not dried properly. To guard against this, it is often wise to educate end users as to the effect of their actions on wood MC. Being aware of what your customers are doing and providing advice to avoid problems is a good proactive stance that will reduce customer claims and maintain better customer relations. The Canadian Wood Council has a publication designed especially for builders entitled "Managing Moisture and Wood – Building Performance Series No. 6". It provides a lot of information concerning "best practices" at the building site to avoid creating moisture issues.

16.8.1 RETAIL SALES AND STORAGE OF DRY LUMBER

The majority of lumber handling situations involve protecting dry lumber from moisture regain. Current trends in retailing lumber at "big box" stores poses the unique problem of the impact of continued drying on lumber quality. To keep customers dry and happy when shopping means keeping the wood in a warm and dry location.

Figure 16-3

Many "big box" stores bring lumber indoors into heated warehouses with low EMC conditions. Wood intended for these markets is sometimes dried to lower MCs to avoid problems with uncontrolled drying while it is on the shelf.



Wood dried to the normal standard for construction grade lumber of 19% and less will lose moisture when stored in a heated building, especially during the winter months in areas with a cold winter climate.

Measures are suggested in the earlier section on storage in "Closed Heated Buildings" on how to minimize this problem. Another way to address the issue is to dry wood intended for this market segment to a lower MC. Drying the wood to a MC closer to EMC of the storage or end use location will minimize the amount of subsequent drying taking place. The problem with this subsequent drying is that it takes place in a situation where the wood is not well restrained and where only some surfaces of boards are exposed to the low EMC conditions. Both of these situations will create more warp in the material raising the amount of reject or unsaleable material.

16.9 LOW OUTSIDE EMC CONDITIONS

Another situation where wood products will get exposed to low EMC conditions is when shipped to certain geographic locations with naturally occurring low RH levels. Take for example, material shipped to Phoenix, Arizona. As shown in Table 16-2, the outside EMC conditions at this location are around 6% during the summer months. Such a dry environment creates an enormous potential to further dry wood products, especially those that have been dried to just below the 19% level for construction grade wood. In this situation it is impossible to modify the EMC level to which the wood is exposed. There are two possible ways of dealing with the problem. The first is to dry material for such markets to a lower MC so that there is less potential for further drying when the material reaches its destination. The second option is to avoid shipping material or products that are warp-prone. As discussed in Chapter 17 the presence of certain physical characteristics in wood will make it more likely to develop warp when dried. By using species or grades of wood that have a lower incidence of these characteristics the problem of warp related to further drying will be minimized. The wood may continue to dry when it reaches its destination but it will not develop as much warp.

The problem of warp related to subsequent drying of solid wood products is often aggravated when the wood is assembled into some sort of composite product. Laminated beams or panels are an example of products that will warp if they continue to dry after assembly. Often the warp is the result of one or more of the pieces in the assembly developing excess shrinkage due to some

abnormal grain characteristic such as compression wood or slope of grain. Again the best way to address the problem is to either implement procedures to eliminate such pieces from the process or dry the material to a lower MC.



DRYING DEFECTS AND THEIR CONTROL

17.1 OVERVIEW

The drying of SPF lumber by all practical methods presently used is accompanied by shrinkage. In itself shrinkage is not a defect but most drying defects are a direct result of shrinkage and the resultant stresses. It is important to understand how the stresses develop, the problems they cause and the measures necessary to minimize damage to the wood.

17.2 STRESS DEVELOPMENT

When a very thin [less than $\frac{1}{2}$ -inch (12.5 mm) thick] piece of wood dries, it does so quite uniformly, so that all of the piece dries and shrinks together. No shrinkage problems should be encountered. With thicker lumber however, drying proceeds more or less layer by layer, with the outer faces and edges drying first and this dry zone gradually moving towards the center of the cross section of a piece.

An important stage is reached when all of the free water in the outer layers, referred to as the shell, has been removed and removal of the bound water begins, while the center or core still contains free water. At this point, the shell wants to shrink, but it is prevented from doing so by the core that is still in its wet swollen state. Drying of the shell proceeds, but shrinkage is prevented. The result is a dry shell that is larger than it would have been if it had been able to shrink in the normal fashion. The shell therefore, is in a stretched condition and is described as being in tension. The core on the other hand, is being squeezed by the shell that wants to shrink and it is said to be in compression.

If the tensile stresses are maintained the shell of the wood will retain its stretched condition to the end of the drying process and possibly beyond. Although it will shrink or swell with subsequent changes in MC as determined by the atmosphere where it is placed, it will always be larger than it would have been if shrinkage had taken place unhindered. This piece of wood would then be described as being set in a stretched condition and

the shell is referred to as being in tension set. This can be compared to an elastic band that has been held in a stretched condition for a long time and will not return to its original size when released.

Similarly, the wet core of the wood that is being compressed at the early stages of drying can take on a compression set. Later, as it dries and begins to shrink, it will shrink more than it would have if allowed to dry without being squeezed by the outer shell and will then develop tensile stress within the core.

In terms of drying defects, stress can cause problems for the end user and this is discussed more in the following sections. The immediate concern during drying is that the stresses do not cause any physical damage to the material. Since wood is much stronger in compression than in tension, it is always the tensile forces that are of most concern. With regard to tensile stress, it is the transverse tensile stress in the direction perpendicular to the grain that is the weakest and it is in this direction that failures will occur. When tensile stresses exceed the strength of the wood, separations develop between the wood fibres. These separations are referred to as checks and are discussed in detail in a later section. One distinguishing feature of all checks developing as a result of drying stress is that they always run parallel to the direction of the wood's grain. Splits or separations in wood fibre developing in other directions are nearly always the result of other wood quality factors.

17.3 CASEHARDENING

The term "casehardening" has long been used in the lumber drying field to describe a stress condition that exists within the wood either during or, remaining in the wood, after drying. It is this stress condition that is described in the following sections. Within the SPF industry, the term "casehardened" has become associated with a very dry shell and relatively wet core condition that can develop in slower drying pieces of wood exposed to a harsh drying environment. In some ways both conditions are

similar in that they are a natural consequence of drying and both become more severe if a faster drying schedule is employed. This section deals with the stress condition known as casehardening. Chapter 15 describes schedule modifications that can address the steep moisture gradient condition referred to as casehardened.

17.3.1 DEVELOPMENT OF CASEHARDENING.

Casehardening is a term used to describe a particular distribution of stresses which are found in lumber after drying. It is important to follow the step-by-step development of casehardening as it develops during drying so that appropriate measures can be taken to correct it where necessary. The stresses that contribute to casehardening are also the same as those which can cause surface and internal checking. In the early stages of drying the shell is restricted from shrinkage by the non-shrinking core that is still above fibre saturation point (FSP). The shell therefore is in tension while the core is in compression. Ultimately, a tension set develops in the shell and a compression set develops in the core.

Later in drying the core begins to dry below FSP and it therefore begins to shrink. If compression set had developed earlier then shrinkage of the core will tend to be greater than it would have otherwise been. When the core begins to shrink it is at first aided by the shell which had been stretched while trying to shrink. The shrinkage of the core is said to relieve some of the tension stresses in the surface layers. However, as the core continues to shrink as it dries, it is prevented from doing so by the shell which has a tension set; that is the shell is fixed in a stretched condition.

The stresses start to reverse at this point; the shell goes from a stretched condition to a tendency to be pulled by the core, and it therefore becomes compressed or goes into compression. The core goes from a compressed condition to being pulled by the surface shell and it therefore goes into tension.

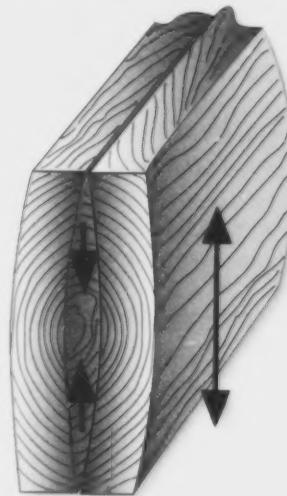
This condition is known as casehardening. The surface is in compression and the core is in tension. If the surface and the core could be separated at this point the surface would enlarge and the core would shrink. If a process to relieve these stresses is not included in the drying routine, this casehardened stress condition will persist in the material long after drying.

The casehardening condition is the normal result of kiln drying but the severity of the condition can be influenced by the drying conditions which are used. If a

board in this condition is turned on edge and resawn lengthwise, the two halves will cup towards one another (Figure 17-1). This is because by cutting the wood at this time and in this manner an imbalanced stress condition develops. Each of the resulting boards has one face containing wood fibre that was formerly (before cutting) under tension and the other face, from the core of the board, that was under compression. The face that was originally the outside surface will enlarge and the new face (formerly the core of the single piece) will shrink and cupping will result.

Figure 17-1

When re-sawing material in a casehardened state the resulting unbalanced stresses may cause boards to distort such as the cupping shown here.



In any manufacturing process which involves resawing lumber lengthwise or removing substantially more from one side of a piece than from the other (as in producing a molding), the presence of casehardening will cause problems. Casehardening is not a problem for many softwood lumber end products since the material is not being remanufactured in this manner. If left as a solid cross section a balance is always maintained between the compression stresses in the shell and the tension stresses in the core.

There are other instances where casehardening or residual stress in wood can cause problems for either the customer or next user of the product. When any sort of precision machining is done on wood containing residual drying stress there is always the possibility that it will change shape or size somewhat. For example, if wood is being machined for fingerjointing or notched for an I-joist flange, the presence of severe casehardening can cause the wood to "move" such that the quality of the joint being produced will be affected. In these and other cases, the solution is to incorporate a stress relief component into the drying schedule.

17.3.2 DETECTION OF CASEHARDENING

When it is known that lumber is being dried for further manufacturing processes, it is wise to check how great the imbalance is between shell and core stresses. The usual method used for detection begins by sawing a strip about one-half to 1-inch (12 to 25 mm) long in the along-the-grain direction at least 18 inches (46 cm) from the end of a board from the kiln charge being dried. If the test strip is cut from nearer to the board end, stresses will not be representative since most of the drying here has occurred along the grain, and smaller differences in MC between the shell and core have developed.

Each strip is then slotted by a number of saw cuts running from one edge parallel to the original board faces. The cuts are stopped about 1/2-inch (12.5 mm) from one end to hold together the prongs so formed. Those steps are indicated in Figure 17-2. For nominal 2-inch (38 mm) lumber it is often sufficient to cut a sample with only the outer prongs left in place as shown in Figure 17-2(b).

Severe drying stresses can be detected immediately by the movement of the outer prongs. To eliminate any shrinkage stresses which are due solely to MC differences between the shell and core, the sets of prongs should be allowed to stand for one day in a warm room. During this time all the wood will arrive at a uniform MC. The condition of the prongs will now give a precise indication of the presence of casehardening as indicated in Figure 17-2(c) and (d). If the wood is casehardened the prongs will pinch inward and if there are no drying stresses present the prongs will remain straight.

The saw cuts allow each prong (which represents a layer of wood across the cross section) to move according to any stresses present. Wood that is in tension contracts and wood that is in compression expands. If the prongs are straight at this time, it indicates that there are no casehardening stresses present and the lumber could be resawn or otherwise machined with no danger of warp or movement developing due to drying stresses.

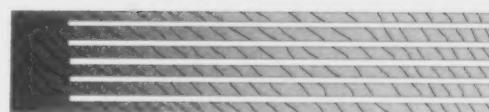
If the outer prongs pinch inward, this indicates casehardening which must be removed if the lumber is to be further manufactured.

17.3.3 CONDITIONING TO RELIEVE CASEHARDENING STRESSES

Casehardening originates from fast-drying and the rapid development of a large difference in MC between the shell and core. The tendency towards casehardening is

Figure 17-2

Pattern for cutting a prong test to detect presence of stress in lumber. Straight prongs as in (b) indicate no drying stress, (c) depicts a stress condition early in drying and (d) a casehardened state that typically exists at the end of drying (prior to conditioning).



a) Test piece for determination of casehardening. Inner prongs should be broken off.



b) Test piece, showing sample of lumber free from casehardening.



c) Test piece, showing casehardening in lumber partially dry.



d) Test piece, showing casehardening in lumber at end of drying period.

greater in thick lumber than in thin lumber, in impermeable slow-to-dry species than in permeable ones, and in rapid forced drying conditions than in slower drying conditions. In general, drying stresses will be minimal, or non-existent, in air-dried wood, moderate in low-temperature-dried wood and progressively more severe as drying temperatures increase and drying times decrease.

In order to minimize the development of casehardening in lumber that is to be further manufactured, an operator must try to keep the surface of the wood at as high a MC as possible without excessively slowing the rate of drying. In effect, this means drying in humid conditions rather than in very dry conditions.

If, at the end of the drying period, it is found with the prong test that an excessively severe casehardening con-

dition is present, so that further manufacturing processes would be difficult, then a special stress-relief treatment must be given. The basis of this treatment is that wood becomes more plastic (soft) if its temperature and MC are raised. When the wood is made more plastic it can yield to any stresses present and the stresses can then even themselves out.

In practice this treatment is applied by raising the temperature and humidity in the kiln. This is frequently done by simply allowing saturated steam to enter the chamber. Other means of raising the humidity in the kiln, such as those listed in Chapter 8, Section 8.7 can also be used. The goal is to raise the humidity level in the kiln to achieve a wet-bulb depression of 8 to 10°F (4 to 5°C). Under these conditions, the wood will regain moisture at the surface and a process of internal stress relaxation is achieved. This procedure is more effective, and more often required, when wood is dried to lower final MCs. As an example, lam-stock dried to 12% is more likely to need conditioning than regular grade lumber dried to 19%.

The end point in the treatment is rather difficult to determine and a real danger exists if the process is continued too long. The only way to determine the time required for conditioning is to cut frequent stress samples. Once a conditioning time has been identified for a particular product and kiln, this time can be applied to future charges avoiding the need to cut multiple charges. If wood is being supplied to a customer who is concerned about drying stress, it is still advisable to cut stress samples on every load. Four to six samples are usually sufficient. The results of the stress evaluation can be stored electronically or on paper by placing the samples on a computer scanner or photocopier and producing an image that can be saved as part of the drying record.

Figure 17-3

To record the stress condition present in the material, stress samples can be scanned or photocopied and the resulting image stored with the drying records.



The result of too much stress relieving is to reverse the stresses that were present, so that now the shell is in tension and the core is in compression. This condition is known as reverse casehardening and is identified when the outer prongs in the stress sample fan outwards. This is a serious condition as it cannot be reversed unless the wood is completely soaked and redried.

For this reason, stress relief is a treatment that requires much attention from a kiln operator. When drying the same species and sizes under the same drying conditions, it will soon become apparent how long the treatment must be continued.

17.4 CHECKING

In the description of casehardening, much was said about drying stresses caused by unequal shrinkage. If the stresses are so severe that the wood cannot withstand them, then wood failure will occur in the form of a check or split. A check may be defined as a separation, formed during drying, of the wood cells extending longitudinally along the length of a piece.

Depending on how and when the stresses due to unequal shrinkage develop, different kinds of checks can be found. Unequal shrinkage has three principal causes:

- As described in relation to casehardening, the difference in shrinkage between shell and core during drying.
- The difference in shrinkage in the radial and tangential directions of the wood.
- The difference in amount of shrinkage between normal wood and compression wood.

In general, checking is caused by unequal shrinkage in adjacent areas of wood. The following sections describe the nature and cause of the principal types of checks.

17.4.1 END CHECKS

End checks (Figure 17-4) are caused by too rapid drying of the ends of boards. Wood dries more rapidly along the grain than across it and this effect extends for up to 18 inches (46 cm) in from each end of a board. Obviously drying is most rapid at the extreme ends. The ends, therefore, tend to shrink much sooner than the remainder of the piece which will resist the shrinkage, thus placing the ends into tension. If the tension stresses are greater than the strength of the wood, then checking will result.

Figure 17-4

End checking results from rapid drying and shrinkage of wood at the end of a board long before the remaining portions of the board have reached the fibre saturation point (FSP).



End checking is more prevalent in wide boards since the transverse stresses that develop are inherently greater. End checking is also more of an issue in air-dried material rather than material that is kiln-dried from the green condition. This is in part because under the accelerated drying conditions in the kiln there is less differential in drying rate between board ends versus mid-portions. This is aggravated in some areas of the country by very low outside EMC conditions at certain times of the year. End splits are also more common in flat-sawn boards because width shrinkage in flat-sawn boards is about double that of edge-sawn boards.

One solution to this problem is to coat the ends with a moisture resistant coating, thereby slowing down the drying and the shrinkage. While this is economically feasible with large or valuable timbers, it is generally not done when drying SPF dimension lumber. Rather, the common practice is to trim back the ends to remove severe end checking at the planer mill. Trim losses are a drying defect and should be counted that way when evaluating a drying operation.

Another approach to reducing these losses is by taking great care in the construction of stickered loads of lumber being placed in a kiln. Loads should be constructed so that no ends protrude and the outermost stickers should be flush with the ends of the lumber. In this way air circulation will be impeded at the ends of the boards and the differential in drying rate versus mid-portions of the board reduced.

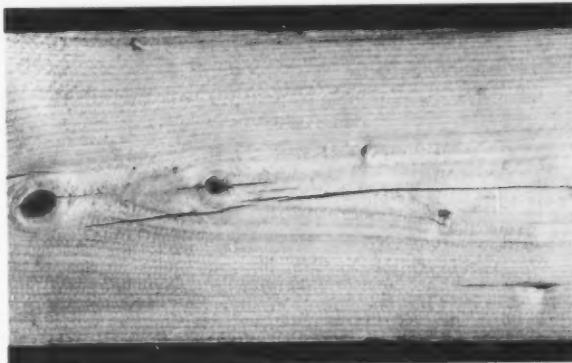
End checking due to air drying can be reduced by taking other measures to slow down the drying rate from board ends. Placing package ends close together in the yard will minimize the amount of direct sunlight hitting them and reduce air flow. Some mills have draped a plastic mesh fabric over package ends to achieve the same effect.

17.4.2 SURFACE CHECKS

Surface checks of lumber as shown in Figure 17-5 are caused by the surface layers drying and shrinking faster than the core. As described under casehardening, early in drying, tension stresses develop in the shell and if these are greater in magnitude than the strength of the wood, checks will develop. Surface checking is more common in the early stages of kiln drying than in later stages since when the MC is higher, the wood is weaker and less capable of withstanding stresses.

Figure 17-5

Rapid drying of the surface, especially in impermeable wood, may generate drying stresses sufficient to cause a separation of wood fibre (surface checking).



Surface checking is more likely to occur in flat-sawn and wide boards, since shrinkage across the width of flat-sawn boards is about double the shrinkage across edge-sawn boards. The difference in shrinkage between a drying surface and a still swollen core will, therefore, be correspondingly greater.

Generally, surface checks formed during the early stages of drying will close as drying proceeds and the inner layers start to shrink. The checks become almost invisible on the surface of boards and very difficult to detect. The checks may close but the damage to the wood is done and under some conditions they may open up again, even after the wood is in service (see internal checks below). Sometimes they will close on the surface, but will remain open further down in the board to become a form of internal check.

Stresses are an inevitable part of drying. Successful drying of wood free of surface checks requires control of the drying rate in order to minimize MC differences between shell and core. In general this means using a schedule that maintains higher EMC levels and perhaps accepting a slightly longer drying time.

17.4.3 INTERNAL CHECKS (ALSO KNOWN AS "HONEY-COMB")

Internal checks or "honeycomb" can be the result of an extension of surface checks or may be the result of internal tension stresses that develop toward the middle and later stages of drying.

Figure 17-6

Internal checking, or honeycomb, may be the result of an extension of surface checks and/or drying of the core after the surface has achieved a stretched "set" condition.



As drying continues beyond the initial stages, progressing layer by layer from the surface inwards, the core eventually dries below FSP and tends to shrink. Shrinkage of the core is restricted however, by the outer shell which was forced to dry in an enlarged condition (shell tension set in the initial stages of casehardening). A tension stress is set up in the core and, again if this stress is greater than the strength of the wood, the cells will tear apart and internal checks will result.

The prevention of internal checks is based upon not creating too great a MC gradient between the shell and the core for those species and sizes which are known to be prone to internal checking.

Wet pocket species are prone to the development of internal checks. Due to the low permeability and high MC of this wood it is more likely that the severe moisture gradient conditions described above will develop. In some cases these internal checks will develop after the material has been trimmed back to expose a fresh board end with a still elevated internal MC.

17.5 KNOT DAMAGE

Certain grades of lumber can be downgraded if knots check, become loose or fall out leaving holes as shown in Figure 17-7. Even structural grades of lumber may be downgraded due to loose or missing knots. In pine species in particular, knots may be encased in resin and, if too high drying temperatures are used, the resin becomes brittle and is broken up in the planer allowing knots to fall out. Knots dry and shrink faster than the surrounding wood causing another situation with differential drying rates. Damage to knots can only be prevented by slow drying and by targeting as high a final MC as possible in order to minimize shrinkage. For the most part, knots in SPF lumber are quite small, well scattered around the board, and do not cause a problem during drying.

Figure 17-7

Drying conditions can contribute to loosening of knots.



17.6 WARP

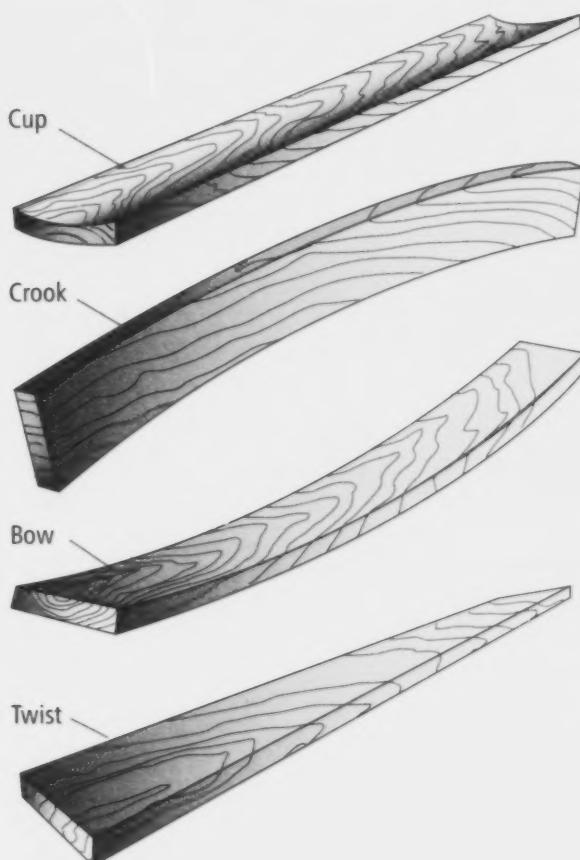
Warp may be defined as any form of distortion which occurs during milling or drying of lumber. Warp is the result of differential shrinkage between one face or edge of a board versus another. The differential shrinkage may be the result of normal differences between radial, tangential and longitudinal shrinkage. Differential shrinkage may also be the result of wavy or distorted grain, compression wood or juvenile wood. The common forms of warp are shown in Figure 17-8 and described in the following sections.

17.6.1 CUP

Cup is the shape taken when a board develops a curvature across the grain. Flat-sawn lumber has a natural tendency to cup when drying, since shrinkage is greater on the face which is most parallel to the growth rings; that is, on the sapwood side. Cupping is also the distortion which results from resawing casehardened lumber

Figure 17-8

The four principal types of warp that develop in lumber as it is dried.



as described in the section on casehardening. Another situation that can lead to cupping is if boards dry more, or more rapidly, on one face than on the other. This is why the practice of drying wide, 1-inch (25 mm) lumber with stickers between only every second row should be avoided. Using more stickers and incorporating good piling practices, as described in Chapter 12, are the best preventions against cupping. Cupping will be more of a problem in wider boards and boards cut either from small logs or from close to the pith of the tree. This is because the greater ring curvature in these pieces creates a greater differential in shrinkage between the two opposing faces. The greatest losses due to cup occur in planing since the pressure of planer rollers will cause severely cupped boards to split.

17.6.2 BOW

Bow is the shape taken when a board develops a curvature along the grain, so that the wide faces become concave and convex in a longitudinal direction. Bow is frequently due to the presence of reaction wood along

one wide face resulting in an abnormally large amount of longitudinal shrinkage on one face only. Good sticker restraint will help to minimize this problem.

17.6.3 CROOK

Crook is similar to bow in that it is the shape taken when a board develops a curvature along the grain, but this time the narrow edges become concave and convex. Crook is frequently due to the presence of reaction or juvenile wood along one edge so that significant longitudinal shrinkage develops along that edge only. Since it is a sideways deflection, the stickers are less able to restrain movement in this direction to reduce crook. Good lumber size control is important in order to maintain some restraint on all boards. As with all shrinkage related defects, crook is made worse by over-drying.

17.6.4 TWIST

Twist is the shape taken when a board develops a spiral-like distortion along the grain so that the four corners of any face are no longer in the same plane. Twist can result when a spiral-grained log is sawn or when a straight-grained log is sawn so that lumber with diagonal grain is produced. This means that the length of wood cells runs at an angle to the edges and faces of a board instead of parallel to them. Normal shrinkage during drying, therefore, is slightly in the longitudinal direction and the board twists.

Twist is a particular problem in lumber sawn to enclose the pith since the wood nearest the pith, juvenile wood, often has spiral grain and has an unusually high component of longitudinal shrinkage. It is for this reason that twist is a problem in drying wood sawn from young trees or plywood peeler cores. Twist-prone lumber must be sawn to minimize thickness variation since good contact with stickers is essential to restrain movement during drying. A combination of high-temperature drying, closer sticker spacing and clamps or weights on the top of loads has been shown to almost eliminate the problem.

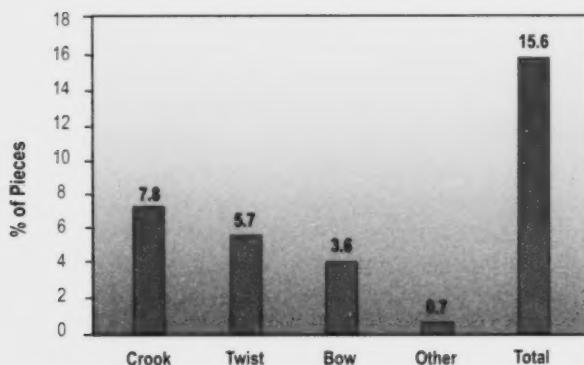
17.7 INCIDENCE AND ECONOMIC IMPACT OF WARP

Several Forintek studies have investigated the incidence and causes of warp in SPF dimension lumber. Of the four types of warp described above, crook is by far the most frequent form of warp causing a board to be downgraded in industrial drying operations. Twist is the second most frequent cause for downgrade due to warp. Figure 17-9 shows the relative amounts of material downgraded by warp type. Overall levels of downgrade due to warp are

not high; more boards are downgraded due to natural defects than to drying defects. However, drying defects are often thought of as avoidable forms of downgrade and it is therefore important to take measures to minimize the impact. The two most important things that can be done in this respect are final MC control (preventing over-drying) and implementation of good piling and handling practices.

Figure 17-9

A Forintek study of industrial SPF drying operations showed that crook and twist are the most common reasons for a board to be downgraded after drying.



A Forintek study at seven industrial Eastern SPF drying operations showed the average value loss due to drying to represent approximately 6% of the potential dry lumber value. Virtually all the value loss was due to warp. Individual mills varied from a low of 2% to a high of 9%. Since these mills were all dealing with a similar resource mix, the wide range of results shows that there is a pay-back from implementing good practices. Figure 17-10 shows the impact of final MC on drying degrade. This highlights the importance of final MC control. Material at the lower end of the MC range exhibited roughly twice the value loss when compared to material close to the final target of 19% MC.

The same study showed that drying degrade in the upper 10 to 15 rows of lumber is roughly twice as high as that experienced in the lower portions of the kiln load, as shown in Figure 17-11. Therefore, there is a benefit associated with applying top restraint. Details on types of top restraint systems are provided in Chapter 12. Losses in the upper rows can be brought back to levels more typical of the rest of the load through the application of top restraint of about 100 pounds per square foot (500 kg/m^2).

Figure 17-10

Value loss due to drying degrade as a function of final moisture content.

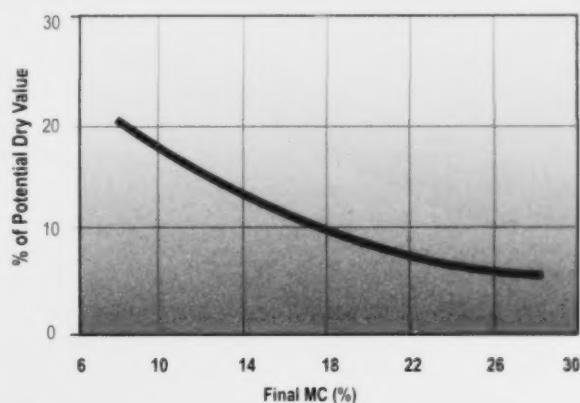
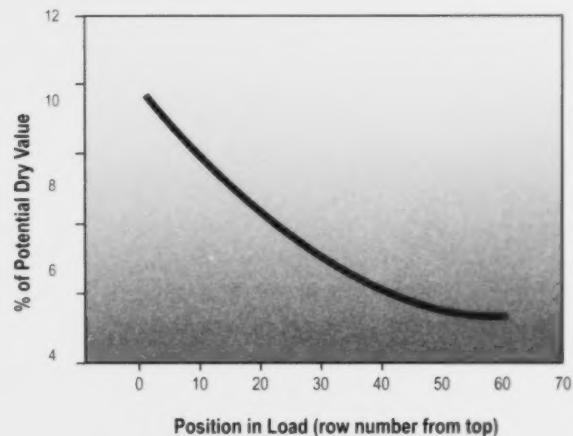


Figure 17-11

Drying degrade as a function of position within the kiln load. These test results are for drying without top restraint and show the potential gain from applying restraint.



17.8 MISCELLANEOUS DRYING DEFECTS

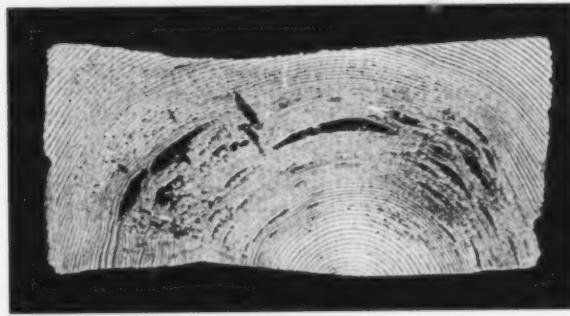
17.8.1 COLLAPSE

Collapse is an abnormal type of shrinkage which distorts, flattens or crushes wood cells. The commonly accepted theory for explaining the phenomenon of collapse is as follows: in very wet wood, the cavities of a number of cells may be entirely filled with liquid free water with no room being left for air. As these cells dry, air should enter the cell cavities to replace the free water moving out. The passage of air through wet wood is very slow however, and the free water can pass out of the saturated cells faster than the air can enter. When this happens the cell walls are drawn together by capillary tension forces and they will buckle and fold to the extent that the cell cavity is completely closed. Note that it is not the

external air pressure on the outside of the wood which is responsible for this collapse, but rather the cohesive force of the water pulling the wet cell walls together. The collapse of groups of many cells produces sunken areas in the surface of lumber giving a washboard effect and in thick lumber internal checks may also develop.

Figure 17-12

Severe collapse and shake in a sample of balsam fir dried rapidly.



The species that are most susceptible to collapse are those that have a very high initial MC – at least in portions of the wood – and have a low density. The low density equates with thin cell walls which are weaker and less able to withstand the stresses described above. Of the SPF species balsam and subalpine fir are the most likely to experience problems with collapse. High MC boards from white and red spruce are also likely to develop collapse.

Collapse is avoided by using milder drying conditions at the start of the drying schedule. This slows drying and provides time for some air to enter the cells and reduce the stress levels.

17.8.2 RAISED GRAIN

This corrugated appearance of the surface of some softwood lumber, known as raised grain usually develops when lumber is not dried to a uniform low MC before it is planed. In flat-grain lumber corrugation of the surface is due principally to the planer knives crushing the hard latewood into the softer earlywood beneath it. Later due to mechanical springback or moisture pick-up, the latewood rises above the earlywood cells causing the rippled surface effect. In edge-sawn lumber that is planed when dry, but which then absorbs moisture, a corrugated surface is caused by greater swelling of the latewood bands above the earlywood bands.

17.8.3 SHAKE AND LOOSENERED GRAIN

Shake or ring shake is a natural defect in the wood that is sometimes associated with or attributed to the dry-

ing process. Shake is a separation or weakness of cells along the border between one annual ring and another. This separation may not be apparent when the wood is green but will often open up as the wood is dried and normal drying stresses develop. Shake may develop from mechanical stresses exerted on the standing tree (i.e., wind) or may be associated with wetwood as described in Chapter 4.

The defect known as loosened grain most frequently occurs on softwood lumber having very dense latewood, in which the shrinkage of the latewood in one annual ring is much greater than that of the earlywood in the adjacent ring. This difference in shrinkage may cause a plane of shear to develop between the two rings. The consequent separation of the annual rings will cause slivers to occur near the surface which when pulled, will often tear along the length of the board.

The occurrence of loosened grain is aggravated by the use of too low a RH during the kiln drying process. This does not mean that low RH will always cause loosened grain, but rather that certain classes of timber are prone to develop this defect under faulty drying conditions. In species prone to this defect or containing naturally occurring shake, the pounding of the wood by improperly adjusted planer knives also can cause separation of the grain at the annual rings, particularly in wood in which there is a considerable difference between the density of earlywood and latewood. Excessive pressure on the feed rolls may also be responsible for this defect in such species.

17.8.4 FUNGAL STAIN

Surface moulds and sapstaining fungi (blue-stain) will develop in some softwood species, particularly pines, if the kiln conditions are set to provide too low temperatures [less than 110 F (43 C)] and high humidity. Sapstain is caused by fungi growing on the wood surface, but can be prevented by rapid drying of the wood surface to reduce surface moisture or by drying at temperatures over 140° to 150° F (60° to 65.5 C). Most SPF drying is done at temperatures well in excess of this and, consequently, sapstain developing in the kiln is not an issue. One area of concern is if lumber is being air-dried. Poor air drying practices can result in slow drying conditions that can lead to the development of sapstain. Long log storage times, over the summer months, can also lead to excessive levels of sapstain.

The presence of sapstain and mould do not negatively affect the grade of most traditional grades of SPF dimension

or stud lumber. New trends in lumber marketing, however, are introducing specialty grades that do not tolerate stain. Since most of these specialty grades are also associated with a higher lumber value, there is an economic incentive to implement measures to prevent or minimize the development of sapstain.

17.8.5 CHEMICAL DISCOLORATIONS

There are a number of colour changes that can occur in wood due to interaction of the chemical constituents of wood with moisture and air. In most cases these are oxidative reactions. None of the species in the SPF grouping are prone to severe chemical discolorations and any slight discolorations that may develop would not affect the grade or marketability of the material.

QUALITY CONTROL MEASURES

18.1 OVERVIEW

Results related to the drying operation are commonly measured by:

- a) productivity
- b) drying costs
- c) quality of the final product (grade recovery and final MC).

In most cases kiln drying adds value to the final product. In addition to the financial incentive, mills dry lumber products to enhance their attributes and to achieve desired dimensional stability. In practical terms, the kiln drying operation probably represents the best opportunity to add value to the final product as long as drying defects do not deteriorate the quality or grade category. For some mills the kiln drying operation is considered as a 'profit centre'. To maximize its profits by adding value and reducing operational costs, kiln operators and supervisors must adhere to well established quality control (QC) practices such as those outlined below.

The three items outlined above (productivity, drying costs and quality) are closely connected. In most cases, increasing productivity means "do more with less" that is, mills try to maximize their present kiln capacity and thereby avoid, or at least postpone, significant capital investments in kiln drying. Selection of drying schedules, sorting prior to drying and the daily operation of kilns (kiln uptime and scheduled and unscheduled maintenance) are the main variables affecting productivity. Mills vary in the way they compute their drying costs. For kilns heated using fossil fuels, energy can be a major component. In most cases, energy and labour are the main components of the cost of drying. Quality of the final product is perhaps the most important measure for any kiln drying operation. The assessment of quality has a tangible component (measured through degrade and MC assessment) and an intangible component that relates to how the customer perceives the quality of the final product. For example, two similar

KD 2x4x16' boards may fall in the same grade category, as defined by lumber grading standards, but due to differing amounts of actual warp, they may be sold for significantly different prices or used in different applications. Thus, more progressive mills use standard grading rules as well as develop their own criteria to match specific customer requirements and thereby maximize the value of their product mix. The role of QC as it relates to drying will increase in importance as mills optimize their grade (including specialty grade) outturn and face competition with other wood substitute products such as plastic, steel or concrete.

18.2 ASSESSING FINAL MOISTURE CONTENT

18.2.1 SETTING TARGETS

Setting target MC is a strategic decision that should involve kiln operators, supervisors, QC personnel, management, and sales/marketing or customer relations personnel. Product use or application and environment in which the final product will be used must dictate target MC. Thus, depending on the product, where it will be used and the time of the year, different target MCs must be selected to ensure optimum performance. One important consideration when deciding on target MC refers to the maximum variation allowed. There are different ways of assessing MC variation but probably the most useful information can be obtained by:

- knowing the average and standard deviation;
- knowing the range of variation that is, the difference between the maximum and minimum values;
- knowing the proportion of material either below or above a pre-defined acceptable moisture range.

The variables above allow the kiln operator to make decisions about the schedule and/or kilns to be used to achieve the desired results. For example, usually kiln operators drying softwood dimension lumber target their final MC so that all material falls in the range of 10% to 19%. The maximum value of 19% is determined by the

grading rules and the minimum value of 10% is common industrial practice although it may vary from mill to mill. In general, lumber exhibiting MC values lower than 10% tend to warp excessively and therefore can be downgraded, resulting in financial loss for the mill. In other wood processing sectors, more stringent MC targets for lumber products used in the manufacture of high quality furniture and musical instruments are invariably required to ensure product performance. Target MC ranges for some of these products can be as narrow as +/- 1 to 2% MC or less.

18.2.2 METHODS FOR ASSESSING FINAL MC

18.2.2.1 HOT CHECKS

The hot check process is used to assess the MC at the end or very close to the end of the drying process. It is basically an opportunity for the kiln operator to determine whether the drying process should be continued (target MC has not been attained) or terminated. The procedure to conduct a hot check is described in section 14.3.4 of Chapter 14. Although hot checks estimate the MC of a relatively small sample (usually less than 1%), the results give the kiln operator the opportunity to detect variations within the kiln and to use the information to decide when to shut down the kiln.

Consistent gathering of hot check information can be quite useful if it is related to the MC values obtained at the planer mill where each piece can be individually assessed. In some cases, hot check MC estimates will be higher than planer MC values and in other cases lower. In general they differ by 2 to 4% MC and this differential is usually consistent for a particular product. It is important to understand the relationship between these two in order for the kiln operator to decide when to end the drying process and avoid over-drying the lumber.

18.2.2.2 COLD CHECKS

In the same manner as a hot check, a "cold" check can be conducted while the material is still on stickers but after it has been removed from the kiln and cooled to ambient temperature. This may provide an opportunity for mills that are not set up to do so at the planer mill to gather more detailed information on final MC. With the lumber out of the kiln and in a more hospitable environment operators can take the time to sample more locations around the load. The same procedures and precautions suggested for hot checks with hand-held meters need to be followed for this sort of testing.

18.2.2.3 OVEN-DRY TESTS

Oven-dry tests are considered the most accurate method

to determine MC of wood – green or dry. However, since the oven-dry test method is time consuming it is rarely used in day-to-day operations dealing with softwood dimension lumber. The procedures for conducting an oven-dry MC determination are described in Chapter 5. A good quality control program will use this method to check calibration of their hand-held and/or in-line moisture meters on an intermittent but preferably regular basis. Every lumber drying operation should have equipment available and personnel able to conduct an oven-dry test (See Chapter 5).

18.2.2.4 IN-KILN MC MEASUREMENTS

Although in-kiln MC measuring systems were developed more than 20 years ago, it is only recently that the technology has gained acceptance by mills drying softwood dimension lumber. There are several suppliers of such systems in Canada. The main advantage of in-kiln MC meters is the potential to end the drying process at the most appropriate point, without excessive amounts of either over-dried or "wet" boards. In-kiln meters normally assess the MC in up to eight different zones throughout the kiln and the combined number of pieces involved in the assessment represents 3 to 5% of the total number of pieces inside the kiln. This is an improvement in terms of proportion of material sampled when compared to the hot check procedure. In-kiln MC meters can also be used to detect significant differences in MC between the eight zones. Kiln operators can then adjust their schedules or residence times based on the differences in MC. Since in-kiln MC meters measure the MC for a group of pieces in a zone (200 to 250 pieces per zone depending on lumber dimensions), it does not give an idea of the variation within the packages. Thus, kiln operators do not have the option with this equipment to assess board-by-board variability or estimate the standard deviation.

18.2.2.5 QC-MC CHECKS (DURING GRADE CHECKS)

Final MC checks are routinely carried out by QC personnel. Mills set their own standards and sample size when carrying out QC-MC checks. In many mills a sample extracted from a shift production involving 100 to 200 pieces is used to assess grading accuracy and this provides an opportunity to collect information on 'types of defects' and 'causes of degrade'. Other mills carry out random checks and select one or more packages per grade per week. A package of 2x4 can contain as many as 480 pieces. In either case the sampled material can also be tested for MC using handheld electric meters (DC-resistance or dielectric types). Mills that produce machine stress rated lumber (MSR lumber) also assess MC using electric moisture meters during their standard

MSR testing procedures. All of these situations are opportunities for the kiln operator to gather data on the final MC characteristics of the dry material.

18.2.2.6 PLANER IN-LINE MC MEASUREMENTS

Moisture content values obtained at the planer are ultimately accepted as the final MC at the end of the manufacturing phase. This is the only opportunity in the process to assess the final MC of every board being manufactured. This is an important assessment as it provides the opportunity to downgrade and/or remove any piece if the MC is above the upper acceptable level set by standards or the customer. Thus, it is imperative that in-line moisture meters are constantly checked for accuracy and mill personnel should follow maintenance and operational procedures according to the instructions supplied by the manufacturers. Some mills have the capability of tracking packages as they come out of the kilns and are processed through the planer mills. This is the ideal scenario since it will be possible to assess MC for a specific kiln charge (drying run) and not only obtain the average MC and standard deviation but also obtain a detailed MC distribution profile according to package location within the kiln. Kiln operators can then troubleshoot their kilns and kiln schedules using the tracked information obtained at the planer mill.

18.2.2.7 CUSTOMER MC CHECKS

As the name implies, customer MC checks are usually carried out for the lumber delivered to the customer. In some cases, the inspection is conducted before the lumber leaves the mill but most commonly, MC checks are carried out at the customer location. In general, customer MC checks are carried out once the lumber has been delivered and is initiated due to a disagreement regarding the value of the final MC. In most cases, mill QC personnel are involved with the customer in deciding criteria for acceptance and/or rejection of the delivered product. Kiln operators rarely get involved with customer MC checks but it is important that they receive feedback from QC personnel regarding the results of the inspection.

18.2.3 ASSESSING FINAL MC VARIATION

Assessing final MC variation is an important aspect of QC procedures associated with the drying operation. It can provide useful information so that kiln operators can modify their drying schedules. It will allow mill managers to evaluate the potential benefits of sorting prior to drying and it also allows maintenance supervisors to troubleshoot areas in the kiln that may be causing variations in drying rates that result in significant variations

of final MC. There are several means for assessing MC variation and the discussion below involves the most practical ones.

18.2.3.1 AVERAGE AND STANDARD DEVIATION

Average final MC (MC_{avg}) is probably the most common parameter used to assess MC at the end of the drying process. Today's moisture meters are designed so that kiln operators can obtain average MC by simply pressing a button after measuring the MC of a number of pieces. It is easy and quick to obtain, but average MC is of limited value when assessing a charge or load of lumber. To give a more comprehensive view of the results it is necessary to obtain another parameter: the standard deviation (SD). With these two parameters, MC_{avg} and SD, kiln operators can have a much better appreciation of the range of final MC for a particular situation. One of the limitations of SD is that it is based on a "normal" distribution of results. Figure 18-1 shows a distribution of final MC results that would be considered, in statistical terms, as "normal". In this pattern there is an equal and similar distribution of readings occurring both below and above the mean value. Unfortunately, final MC is not a variable that always fits the "normal" distribution as shown here. Despite this limitation it is still a useful tool for comparing drying results from charge to charge and is worthwhile setting a target value for.

In many cases the final MC distribution for individual charges resembles the graph illustrated in Figure 18-2. In comparison to the distribution of readings in Figure 18-1 it can be seen that the readings are now heavier, or skewed, toward the lower MC side. This occurs because the drying rate of wood slows considerably at lower MCs and therefore, pieces tend to accumulate in the lower MC ranges – especially when drying times are extended.

Figure 18-1

Final moisture content (normal distribution assumed).

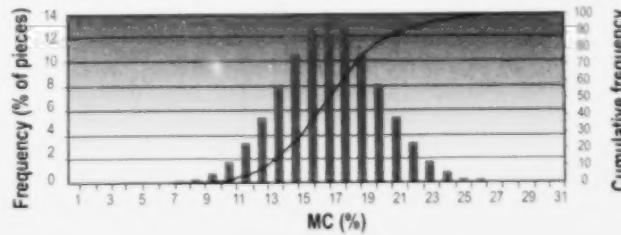
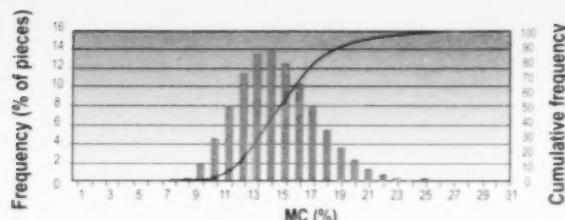


Figure 18-2

Typical final moisture content distribution (skewed).



Standard deviation can still be calculated and used to describe a skewed population but, comparisons to other populations can sometimes be misleading. However, the 'law of large numbers', (known in Statistics as the Central Limit Theorem) provides a means of using the normal distribution rules to advantage. This theorem states that, although the individual sample groups may not follow a normal distribution, the distribution of the charge averages for a number of charges will be normally distributed. Thus, if the average MC values for a large number of kiln charges are plotted, the overall distribution of the final charge average MC for the mill (or kiln, product, etc.) will resemble the graph illustrated in Figure 18-1. Doing some basic statistics on the values of charge average MC will also provide some information on how this property varies from charge to charge. In this case, a standard deviation of 3% tells us that the average MC for individual charges will fall within a range of 12 to 18% MC 68% of the time (based on the definition of SD). The same definition of SD states that 96%

of the results will fall within plus or minus two standard deviations (9 to 21% MC in this case). Quality control personnel can therefore set up not only target average MCs but also a target SD. If a mill sets a target average charge MC of 15% and a SD of 2%, they could expect to see their final charge average MCs fall within the range of 11 to 19% most (96%) of the time.

At the end of the drying process kiln operators can measure MC_{avg} and over time calculate the SD on this property, and thereby develop distributions similar to those illustrated above. The results of this analysis will have additional meaning when they are associated with a specific kiln, product, species, sorting group or time of the year (season). When kiln operators are equipped with this type of information, they can carry out comparison analysis and, as an example, adjust the drying schedules to bring things within the targeted range.

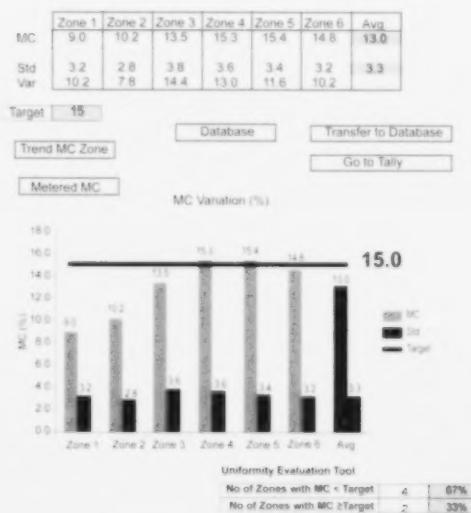
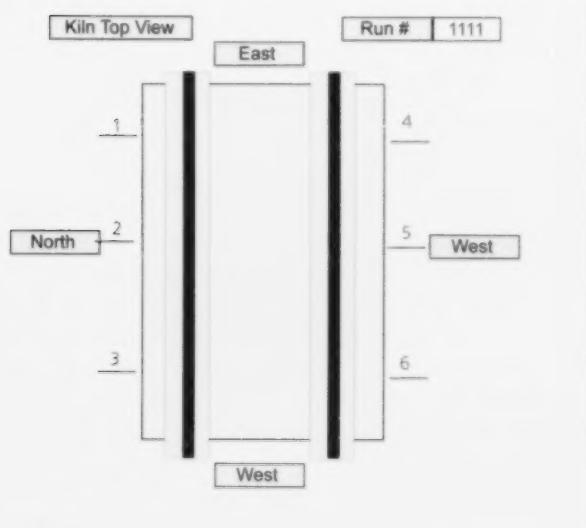
18.2.3.2 LOCATION WITHIN THE KILN

As mentioned earlier, assessing MC based on location within the kiln will allow the kiln operator and maintenance personnel to troubleshoot and fix problems. For example, kiln issues that affect drying rates are usually related to non-uniform air velocity and/or non-uniform conditions of temperature and RH. Figure 18-3 illustrates the assessment of MC for different regions of the kiln.

As shown in Figure 18-3, lumber located in Zone 1 (northeast part of the kiln) is clearly over-dried. There are many reasons that could be contributing to the situation illustrated. Once the trend is identified, kiln operators can start investigating possible causes. In some cases it will be useful to assess the 'degrade' that will probably

Figure 18-3

Assessing MC for different regions of the kiln.



occur for the lumber that was over-dried (northeast location). Determining the financial impact will certainly help justify the investment to address the problem that is causing over-drying. It is quite possible that the reason for the over-drying observed for Zone 1 was due to the lumber in that location within the kiln having been air drying in the yard for some time. Although it is not a recommended practice mills are sometimes forced to load kilns with lumber having different yard history and therefore different initial MCs. If that is the case, displaying the final MC data as illustrated in Figure 18-3 may be sufficient to justify changes in procedures. In this case it may simply be establishing guidelines to ensure that lumber to be loaded in a single kiln charge will have similar yard history. Whenever that is not possible, the kiln operator could then be empowered to use a more conservative drying schedule to avoid over-drying the portion of the load with the lower initial MC.

18.2.3.3 INTERPRETING STATISTICAL PARAMETERS

As discussed above, the average final MC and SD are probably the most commonly used parameters to assess the results of the drying process. Individually, MC_{avg} and SD do not give a definitive idea of the results of a particular kiln charge. Thus, they need to be reported as a pair to more fully describe the results. Figure 18-4 illustrates the distribution for a hypothetical kiln charge for which the MC_{avg} and SD are 11.0% and 3.5% respectively.

Figure 18-5 illustrates another distribution with a different MC_{avg} but the same SD. The MC distributions illustrated in Figures 18-4 and Figure 18-5 show a similar 'spread' (same SD) but significantly different average MCs. The distribution in Figure 18-4 clearly illustrates that a considerable amount of lumber was over-dried whereas the distribution shown in Figure 18-5 depicts reasonable results. Thus, even though both distributions exhibit the same 'spread', the final MC_{avg} clearly differentiates them. Likewise, the scenarios illustrated in Figures 18-6 and 18-7 illustrate the situation where both distributions exhibit the same MC_{avg} = 14.3% but significantly different SDs.

Although the MC_{avg} for the distributions is the same (14.3%), the 'spread' illustrated by Figure 18-6 clearly indicates better results when compared to the results illustrated by Figure 18-7.

Figure 18-4

Distribution of final MC ($MC_{avg} = 11.0\%$, $SD = 3.5\%$).

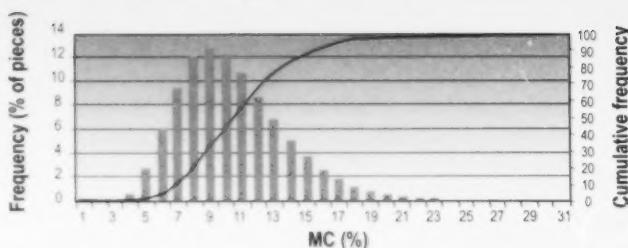


Figure 18-5

Distribution of final MC ($MC_{avg} = 14\%$, $SD = 3.5\%$).

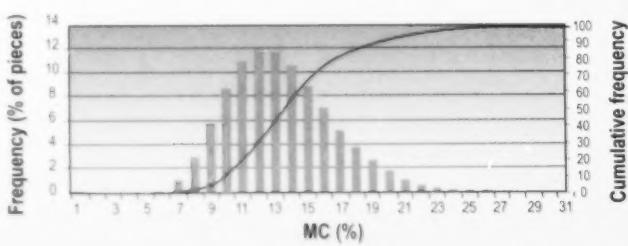


Figure 18-6

Distribution of final MC ($MC_{avg} = 14.3\%$, $SD = 2.2\%$).

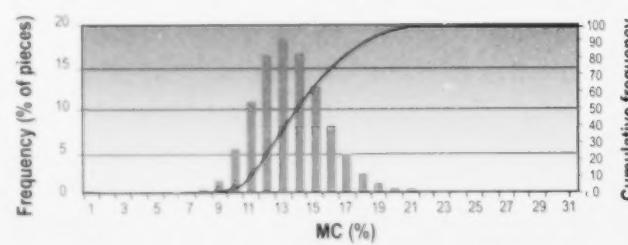
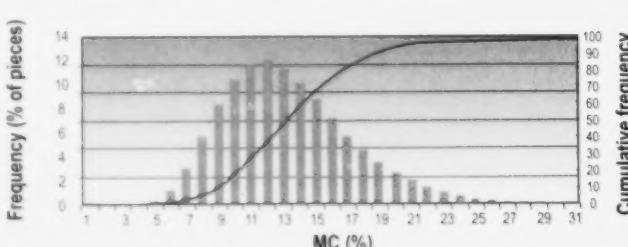


Figure 18-7

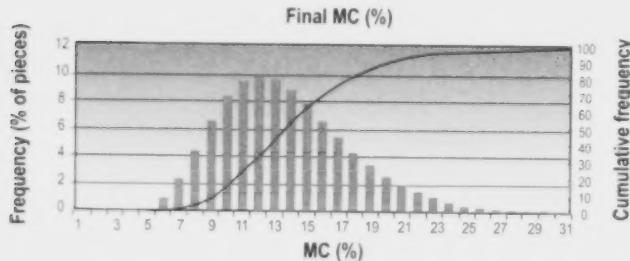
Distribution of final MC ($MC_{avg} = 14.3\%$, $SD = 4.3\%$).



In addition to the parameters of MC_{avg} and SD, kiln operators can get useful information from histograms, MC ranges, and cumulative distributions. For example, the distribution of final MC for a typical kiln charge is illustrated in Figure 18-8. The MC_{avg} and SD are 14.4% and 4.5% respectively. In addition to noting the skewed pattern of final MC, the operator can get an idea of the range; that is, the difference between maximum and minimum MCs. For the example shown in Figure 18-8, the range is 25% (30 to 5%). This graph also has a line added to show the cumulative distribution of final MC. This line can be used to determine the amount of material falling below (or above) a specific final MC value. For example, this graph indicates that about 15% of the lumber has an MC below 10%. Thus the kiln operator can quickly get a good estimate of the amount of over-drying (designated here as material below 10%) and therefore evaluate the effectiveness of the drying run and determine whether there is a need to modify the drying schedule. The graph in Figure 18-8 can also be used to determine the amount of "wet" material or material falling over a pre-defined maximum acceptable MC. In this case, the example on the graph shows that approximately 90% of the load has a final MC of 20% or less. Therefore, there would be 10% of the material with a final MC greater than 20%. Adding the percent of over-dried and under-dried ("wets") material will provide a quick total of the amount of material that falls outside of the pre-defined target range.

Figure 18-8

Distribution of final MC ($MC_{avg} = 14.4\%$, $SD = 4.5\%$).



All the results illustrated by the figures above represent typical scenarios found in industrial drying operations. The main performance indicators, as pointed out in the introduction to the chapter, productivity, drying costs and quality, must be considered when analyzing the graphs above. For example, for operations producing lumber for 'laminated stock' the results illustrated by Figure 18-4 might apparently comply with requirements (MC lower than 14%). However, a closer analysis would

reveal that 15 to 20% of the lumber would have a final MC over 14%. Kiln operators and managers must decide whether the amount of "wets" for this case is too high or if it can be sorted out and directed to different final products. On the other hand if the kiln operator dried the charge to a lower MC_{avg} , most of the lumber would invariably fall below 14%. However, the additional drying would probably cause other problems associated with excessive shrinkage and warp as there would be a larger proportion of over-dried material. Thus, mill QC and kiln operating staff must agree on and set target values for final MC_{avg} , SD, and final MC range. It is quite likely that different targets will need to be set depending on the product, time of year, species and/or customer requirements. This dynamic approach to interpreting results is necessary to optimize the three main components that measure the success of the drying operation (productivity, drying costs and quality of the final product).

18.3 IMPACT OF DRYING ON PRODUCT QUALITY

18.3.1 ASSESSING LUMBER QUALITY

Mills employ different ways of expressing their quality results depending on the products being manufactured and target markets. In many cases, dimension mills express their results in terms of percentage of the production for a certain grade outturn. Mills producing random length dimension lumber normally express their results in terms of 'percentage of No. 2 & Better'. Other grade categories such as Premium, J-grade, Economy and Utility can also be used to provide a comprehensive distribution of quality for the products and therefore allow managers and supervisors to continually evaluate results and compare to other similar mills.

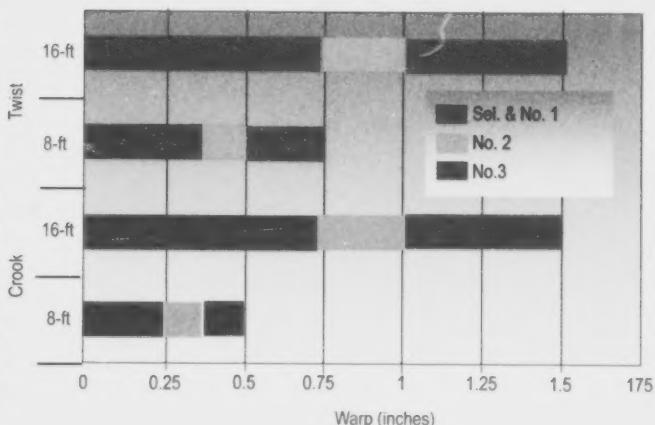
In general when a mill reports that their percentage of No. 2 and Better is 85%, it means that 15% of the lumber did not make it into the higher grades. The reason for downgrade may be the result of natural defects or a problem caused by the manufacturing process, including the kiln drying stage. The process of determining the proportion of material downgraded due to drying can be a difficult and time consuming task but does result in valuable data. Mills often overlook the opportunity to determine the actual cost of degrade due to drying and therefore the potential increase in annual revenue that can be generated through a well run drying operation. Although the potential increase in annual revenue depends on lumber prices and market conditions, improving the drying operation will inevitably result in attractive benefits and payback both tangible (better grade recovery) and intangible (better quality perceived by the customer).

18.3.2 ASSESSING WARP AS A QUALITY INDICATOR FOR DRYING DEFECT AND DEGRADE

Warp is the most significant drying defect affecting the grade of SPF dimension lumber. Thus, if warp can be accurately assessed, it can be used to estimate the impact that, for example, a particular drying schedule will have on the final quality of the product. The diagram below (based on NLGA rules) illustrates the critical limits for various forms of warp in terms of their impact on drying degrade.

Figure 18-9

Actual warp (crook and twist) allowances based on NLGA grading rules for softwood dimension lumber.



There are various ways in which drying degrade can be evaluated for SPF dimension lumber. The method chosen will be determined by the level of detail required. Mills should consider using several of the following options as part of an ongoing program to monitor the level of drying degrade.

1. MONITORING REASONS FOR DOWNGRADE

The regular grade check system employed at many mills can be elaborated upon to gather data on pieces downgraded due to warp. By monitoring the "percent of pieces downgraded due to warp" a mill can pick up on increases that may be the result of equipment or operational problems at the kiln. Some automated grading systems now offer the ability to monitor this performance criterion on a regular basis.

2. MEASURING WARP IN DRY LUMBER

Taking actual measurements of warp in dry lumber can reveal more information on when things are starting to go "out of control" in a drying operation. As shown in Figure 18-9 there are various discrete levels of warp that

define whether a board makes one grade or another. By gathering data on grade recovery alone, the result is a simple "pass"/"fail" evaluation. By gathering and analysing data on actual warp measurements, increases in the amount of warp can be detected before a major impact on grade recovery develops. The best way to measure warp manually is to pull material off line and place it on a flat surface as shown in Figure 18-10. Automated grading systems are evolving and at least some of them now have the capacity to provide data on the actual amount of warp present. Regardless of the manner chosen to gather data on warp in dry lumber, it must be remembered that not all warp is a direct result of drying. Some warp can be imparted to the lumber during the sawing process either from natural growth stresses or curve sawing operations. If these sources of warp can be considered as minimal or constant (this needs to be determined), then variations in warp in the dry product will be, for the most part, a result of the drying operations.

Figure 18-10

Detailed measurements of warp require removing material from the production line and placing it on a flat surface. Newer, automated grading systems may be able to provide similar information.



3. MEASURING WARP BEFORE AND AFTER DRYING

A more accurate but time consuming way of collecting data on warp is to measure the product both before and after drying. This eliminates the problem of existing warp in green lumber affecting the results. This type of test can be conducted manually or with an automated grading system. If using an automated grading system, the packages of green lumber to be assessed would have to be run through the grading system prior to drying. The opportunity to do this will vary from mill to mill and will depend on physical restrictions for getting green lumber

in and out of the grading line and the availability of free time on that line.

4. TRIM LOSSES AS A COMPONENT OF DRYING DEGRADE

With every lumber manufacturing operation there is an element of volume loss associated with trimming at the planer mill. Depending on the product a certain portion of those trim losses will be due to drying defects such as end checking or warp. In order to get a complete picture of drying degrade, a degrade analysis should include at least a quick evaluation of the trim losses to see if this component is significant. Trim losses can be evaluated as part of a "before and after" grading evaluation as detailed in No. 3 above or can be assessed by monitoring dry lumber being processed at the planer mill. If done on line with a manual grading situation, the graders can indicate when a board is being trimmed back and by how much due to a drying defect. Again, automated grading systems may offer an opportunity to collect these data more efficiently.

HEAT TREATMENT FOR PHYTOSANITARY REQUIREMENTS

19.1 OVERVIEW

The Food and Agriculture Organization (FAO) of the United Nations has issued International Standards for Phytosanitary Measures (ISPM) to help control the transmission of forest (and other) pests from country to country or continent to continent. ISPM No. 15 "Guidelines for Regulating Wood Packaging Material in International Trade" lists heat treatment (HT) as an approved measure for wood packaging material.

ISPM No. 5 defines heat treatment as:

"The process in which a commodity is heated until it reaches a minimum temperature for a minimum period of time according to an official technical specification."

ISPM No. 15 states that:

"Wood packaging material should be heated in accordance with a specific time-temperature schedule that achieves a minimum wood core temperature of 56°C for a minimum of 30 minutes."

The footnote for this line states that this combination of temperature and time was chosen *"in consideration of the wide range of pests for which this combination is documented to be lethal and a commercially feasible treatment."* Although these documents relate to wood packaging materials, HT is now accepted by many countries as an effective phytosanitary measure for all solid wood products. For example, Canadian softwood lumber being shipped to Europe needs to meet the above standard in order to be marked or otherwise documented as being heat treated.

Within North America an "HT" designation has been added to the grade stamp for softwood dimension and stud-grade lumber. Most kiln drying operations meet the temperature criteria listed above and are therefore able to include this designation on their material along with a "KD" designation. Material may also be marked as "HT" without the "KD" designation provided an approved treatment has been followed.

19.2 HISTORY OF HT REQUIREMENT

In the late 1980s the European Union identified the pinewood nematode (PWN) (*Bursaphelenchus xylophilus*), which was present in some North American softwoods, as a possible threat to their forests. As a result the Canadian lumber industry needed a way to ensure their product was phytosanitary safe. For the most part, kiln drying was accepted as an effective means of eliminating pests as the majority of kilns operated at temperatures of 160° to 180°F (approx. 70° to 80°C) or higher. However, kiln drying has certain costs associated with it which are only recovered when the customer has requested the lumber in that condition.

In order to develop a lower cost alternative, Forintek and several other Canadian research facilities embarked on a project to identify the lowest temperature and shortest time combination that would eliminate the PWN and its vector, the Monochamus beetle. The results of that work identified 56°C (133°F) for 30 minutes as an effective treatment. This temperature-time combination was recommended after taking into consideration the most temperature resistant isolate of PWN and the worst case combination of wood species and MC.

19.3 EFFECT OF WOOD PROPERTIES ON HT

Physical properties such as basic density and MC have long been known to have an effect on heating time in wood; however, the significance of each of these is not well documented for Canadian species in this temperature range. Wood at a high MC has little air present and wood cells saturated with water are a better conductor of heat than wood cells filled just with air. On the other hand, more water present means more mass and therefore more energy is required to heat the piece. One of the factors limiting heating rate is the surface area in contact with the heated air stream.

An analytical method of predicting heating rate in wood has been developed by Forintek. Results confirm that increasing either wood density or MC will cause an increase in heat treatment time, all other factors being equal. However, wood thickness has by far the greatest impact on total treatment time. Treatment time increases in relation to, and at a faster rate than thickness. If lumber thickness doubles, heat treating time will more than double.

When heat treating green lumber, it is the wet-bulb temperature that has by far the greatest impact on treatment time. This is not surprising if it is considered that a piece of wood that is well saturated will act very much like a wet-bulb sensor. Moisture evaporating from the surface will cause a cooling effect. On very green wood, the surface temperature will not rise above the wet-bulb temperature until some drying has taken place. Therefore, in order to achieve a short treatment time it is essential that the wet-bulb temperature be somewhat in excess of the target core temperature. Work conducted by Forintek identified that treatment chambers operating at a wet-bulb temperature of 60°C (140°F) or higher achieved the shortest heat treatment times [when targeting a core temperature of 56°C (133°F)].

It is possible to achieve a successful heat treatment with wet-bulb temperatures lower than the target core temperature as long as the dry-bulb temperature is greater than the target core temperature. Under these conditions, however, it must be expected that treatment times will be greatly extended. In order for these conditions to be effective, the wood must either be partially dry at the time of treatment or some time must be given within the treatment to dry the surface of the wood. This will then allow the surface temperature to rise above the wet-bulb temperature.

Figure 19-1 shows the relationship between wood temperature, dry-bulb temperature, and wet-bulb temperature during a typical heating phase. As mentioned previously, the temperature of wet wood approaches and follows the wet-bulb temperature more closely than the dry-bulb temperature. Due to the close link between wet-bulb temperature and wood temperature, many of the heat treatment schedules developed for solid wood are based primarily on wet-bulb temperature.

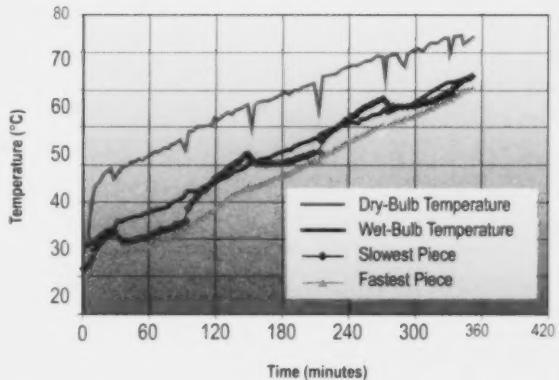


Figure 19-1

Sample heating rate in 2-inch softwood lumber as compared to dry- and wet-bulb temperatures.

19.4 HEAT TREATMENT SCHEDULES

The export of heat treated lumber is regulated by the Canadian Food Inspection Agency (CFIA). The CFIA has developed various programs in which the industry and associations can participate. The options available to industry for heat treatment of solid wood are described in the CFIA document "The Technical Heat Treatment Guidelines and Operating Conditions Manual" (PI-07). Mills can elect to either have a third party develop a site-specific treatment schedule or use a number of "generic" heat treatment schedules. There are two general groups of generic schedules; some based primarily on wet-bulb temperature and others based exclusively on dry-bulb temperature.

The wet-bulb-based generic schedules for Canadian softwood lumber up to 130 mm thick are listed in Table 19-1 and others can be found in the CFIA document PI-07. These schedules list a minimum total treatment time, the portion of the schedule where the wet-bulb must meet or exceed 140°F (60°C) and the final wet-bulb temperature that needs to be attained.

These schedules reflect the actual conditions achieved during industrial heat treatment processes. They are flexible in that the total treatment time must be extended if the wet-bulb temperature does not reach 140°F (60°C) within the allotted time. For example, on material up to 2-1/4 inches (60 mm), if the chamber does not reach a wet-bulb temperature of 140°F (60°C) until 7 hours, 30 minutes into the process, the total treatment time would become 9 hours, 33 minutes (7 hours, 30 minutes to reach 60°C plus 2 hours, 3 minutes over 60°C).

Table 19-1

Generic heat treatment schedules applicable to all Canadian softwood lumber as listed in the Canadian Food Inspection Agency document PI-07.

Maximum thickness inches (mm)	Minimum total treatment time	Time with wet-bulb temp. over 140°F (60°C)	Final wet-bulb temperature °F (°C)
2-1/4 (60)	6 hours, 26 minutes	2 hours, 3 minutes	145° (63°)
3-1/4 (85)	7 hours, 20 minutes	3 hours, 20 minutes	151° (66°)
4-1/4 (110)	10 hours, 57 minutes	6 hours, 34 minutes	153° (67°)

Table 19-2

Low dry-bulb temperature heat treatment schedule for Canadian Softwood species. As listed in the CFIA document PI-07.

Lumber thickness inches (mm)	Dry-bulb temperature run time with temperature over 126°F (52°C)	Minimum time at the end of the treatment with dry-bulb temperature over 140°F (60°C)
Up to 1-1/8 (28)	8 hours	4 hours
Up to 2-1/4 (60)	18 hours	6 hours
Up to 3-1/4 (85)	45 hours	15 hours
Up to 4-1/4 (110)	72 hours	24 hours

Table 19-3

High dry-bulb temperature heat treatment schedule for Canadian Softwood species. As listed in the CFIA document PI-07.

Lumber thickness inches (mm)	Minimum treatment run time	Minimum time at the end of the treatment with dry-bulb temperature over 160°F (71°C)
Up to 2-1/4 (60)	12 hours	6 hours

Other generic schedules based strictly on dry-bulb temperature are also available. Table 19-2 provides the details for the low-temperature, dry-bulb treatment option known as "Option C" within the CFIA document PI-07. Table 19-3 lists the conditions for a higher, dry-bulb temperature-based schedule.

The CFIA document PI-07 and website list a number of other generic treatment options to cover hardwoods and softwoods up to 12 inches (205 mm) thick. The generic schedule options are available to all industry providing they demonstrate that they meet certain operating requirements and register into a CFIA program. A number of industry associations (i.e., lumber grading associations) provide technical and administrative support to the industry to facilitate registration for their members. The site-specific chamber certification process is

still available, however, the generic schedule option is cheaper and easier for most companies to meet the requirements. Companies handling large volumes of material may still benefit from the site-specific procedure as it will result in the shortest treatment time possible.

The above information has been provided as an overview of the current state of HT in Canada. Anyone considering registering their facility to produce heat treated lumber should check with both the CFIA and their grading association to get the most up-to-date and relevant information for their situation.

19.5 PRACTICAL ASPECTS OF HEAT TREATING

The physical aspects of heating a large load of lumber are quite complex. In a very small chamber heating conditions can be assumed to be uniform over time as well

as throughout the treatment chamber. In an industrial kiln, the large volume of wood will rapidly absorb heat at the start of the process and therefore prevent the kiln air from heating up as rapidly as it would in a small test kiln. The ratio of heating capacity to kiln volume will be much larger in a small-scale kiln than in an industrial kiln. Another factor to consider in a large-scale kiln is the variation in conditions across the load. As air flows through the load, it gives up heat to the lumber and its temperature is reduced. This results in a temperature drop across the load which needs to be considered in determining the "worst-case" heating conditions in the chamber. It is the "worst-case" heating conditions that will invariably determine the total treatment time.

For the most part, treatment chambers used to heat treat wood products were built originally, and in most cases are still primarily used, to dry lumber. There are many shapes, sizes, equipment types, capacities and equipment configurations found in lumber dry kilns. Not all dry kilns are necessarily good HT facilities. The following is a brief list of operating features that make a dry kiln (or any chamber) better suited for use as a heat treating facility:

- **High and uniform air flow** – helps reduce temperature drop across the load and improves heat transfer to the wood
- **Uniform temperature distribution** – helps provide even heating along the length and from top to bottom in the kiln
- **Well sealed** – helps retain moisture escaping from the wood and thereby helps maintain a higher wet-bulb temperature
- **Large heating capacity** – typically need a faster heating rate than what most kilns are designed for
- **Humidification system** – ability to add humidity to the kiln air and achieve the desired wet-bulb temperature sooner.

It is not imperative that HT chambers have all the capacities listed above. Kilns that have most of the above characteristics would also be ones that are more likely to benefit from the site-specific approach mentioned earlier. Any kiln that can reach the prescribed conditions in the generic schedules in the minimum listed time will likely be able to attain an even shorter treatment time if tested following the site-specific procedure.

ENERGY CONSUMPTION AND EFFICIENCY

This chapter deals with describing where and how energy is used in drying with the purpose of helping to identify how a drying operation can be made more energy efficient. Efficiencies arising from improved equipment operation and maintenance will be discussed along with technologies to help reduce energy consumption. There are many other documents that go into great detail on how to break down the amount of energy used in drying and calculate specific energy consumption values for each. Some of these are listed in the section on further reading.

The types of energy systems and sources of energy are discussed in Chapters 7 and 8. The subject of energy systems to supply thermal and/or electrical energy requirements for dry kilns is beyond the scope of this chapter and manual. There are many new technologies available to take advantage of biomass fuels to reduce energy costs for mills, make them less dependent on outside suppliers and help achieve a carbon neutral status.

20.1 OVERVIEW OF ENERGY USE

Drying can account for 70% or more of the total energy used to transform logs into lumber. This figure will be quite variable depending on factors such as initial MC, final MC requirements and sizes of lumber produced. Regardless of the precise figure, drying represents the single largest contributor to the overall energy requirements in lumber production. Consequently, all of the typical concerns related to utilization of energy are relevant to lumber drying operations. The two main concerns are cost and environmental issues. An awareness of what energy is used for in drying and how much is used will help operators identify opportunities to achieve greater efficiencies and economies.

Two forms of energy are used in lumber drying. Electrical energy is used to drive motors primarily for the air circulation system but, to a lesser extent, motors for the energy system. A larger amount of energy is used to generate heat to drive the drying process. The relative

amount of electrical to thermal energy used varies considerably by drying system. In some situations, for example dehumidification drying, a large part of the thermal energy required is produced by electrical means.

Energy is also one of the major cost components in drying. Fortunately there are things that can be done to minimize the energy requirements. This includes proper maintenance of equipment, following recommended drying practices and looking for options to run with less expensive fuel sources. Some practical ways of reducing energy consumption are listed later in this chapter.

One advantage the wood products industry has is the easy access to some form or another of wood by-product from the sawmilling process either at no cost or very minimal cost. Most of the conventional drying systems and many of the non-conventional systems offer at least some capacity to inject heat from burning wood fibre or bark. In heat-and-vent kilns this could form the major portion of the energy. However, even in dehumidification and vacuum drying systems there is often the opportunity to supply part of the thermal energy requirements from a combustion system which can just as readily be fired by by-products from the sawmill or planer mill as by fossil fuel. There are many small-scale wood-burning systems available that can easily be adapted to fit a wood drying application. Burning wood residues also has an environmental advantage over burning fossil fuels in that it is "carbon neutral". The subject of energy self sufficiency and reducing the industry's "carbon footprint" are key motivations for seeking out such technology and lumber drying is the logical place to look for opportunities.

Most of the material in this chapter is directly relevant to heat-and-vent kilns but many of the recommendations regarding a more efficient overall drying process are equally relevant to other drying systems.

Regardless of the type of energy used, there will be both economic and environmental benefits from making a drying system more energy efficient.

20.2 THERMAL ENERGY BREAKDOWN

Lumber drying, in any system, invariably involves the evaporation of water present in the wood. Independent of the kiln, green wood consumes a certain amount of heat to raise its temperature, and a certain amount of heat to raise the temperature and subsequently evaporate the moisture present. To illustrate this, consider a charge of green lumber having a MC of 60% and a basic density of 24.9 lb/ft³ (400 kg/m³). Assume that the ambient temperature is 15°C, and that the lumber is to be dried to a final MC of 14% using a constant dry-bulb temperature of 85°C (185°F). It can be easily calculated from this that to dry the lumber will consume 160,000 btu/MBM for warm-up and 950,000 btu/MBM for moisture evaporation. This 1.11 million btu/MBM is the "bottom line", and represents the amount of energy that must be delivered to the wood to dry it to the stated MC. Actual energy consumption may be higher or lower than this value depending on efficiencies and heat losses from the system or the utilization of a drying system that recaptures some of the energy used to evaporate moisture. Any heat required over and above this value is not actually supplied to the wood, but lost somewhere on its way from the energy system to the kiln. This "bottom line" can vary considerably among species and dimensions due to differences in wood density as well as initial and final MC.

In heat-and-vent kilns, thermal energy is by far the most significant energy input to the process. Thermal energy (heat) can be supplied to the kiln directly via hot combustion gases or indirectly through a radiant heating system using steam, hot water or hot oil. Some understanding of how this thermal energy is used will provide some insight into how energy savings may be achieved. Various authors have broken down the thermal energy input into various categories. Work at the University of Maine in the 1970s by Schottafer and Schuller provided not only a means of describing the breakdown of thermal energy used but also a way to estimate the requirements for each. Their work provides the following breakdown for thermal energy use in heat-and-vent drying.

There is a wide range associated with most of the listed thermal energy components because of the diversity of drying scenarios that may exist. As an example, heat losses (item No. 5) will be less when drying times are short, and higher when long drying times are employed. Energy to heat and evaporate water (item No. 4) will not be significantly affected by drying time but will be heavily influenced by initial MC. This list also provides an indication of where a significant impact on energy consumption can be achieved. For example, providing better insulation on the kiln walls may seem like a logical way to reduce energy but, based on the above breakdown, even if the amount of insulation on the walls and roof is doubled, the overall energy consumption would only be reduced by 7 to 15%.

The obvious major opportunity to reduce energy consumption is with respect to item no. 4, "heat and evaporate water removed". Some means of reducing the initial MC, for example air drying, will have a major impact on overall energy consumption. Unfortunately, in a heat-and-vent kiln all of this energy is lost through the vents when the warm humid air is exhausted. This provides an opportunity to re-capture some of this energy. Some equipment manufacturers offer heat exchangers either as part of the initial kiln design or as a retrofit. It is in this area where dehumidification kilns offer an energy advantage over heat-and-vent kilns. Instead of either venting all of this energy or recapturing a small portion of it, a dehumidification kiln operates in a closed loop that retains most of the energy within the system. However, since dehumidification kilns rely on electricity as their primary energy source, this energy reduction does not always translate into an energy cost saving.

20.3 THERMAL ENERGY REQUIREMENTS

As already mentioned, the amount of thermal energy used in a heat-and-vent kiln will vary considerably depending on many specifics related to each installation. Forintek has developed a methodology to assess energy consumption in drying. Based on this methodology, Table 20-2 provides a list of the estimated thermal en-

Table 20-1

Breakdown of thermal energy use during drying.

Thermal Energy Use

% of Total Energy

1. Raise the temperature of the wood	3 to 5%
2. Overcome hygroscopic forces (break chemical bonds between water and wood)	approx. 1%
3. Raise temperature of remaining water	approx. 1%
4. Heat and evaporate water removed	50 to 70%
5. Replace heat losses (walls, roof & floor)	15 to 30%
6. Raise temperature and RH of replacement air	10 to 20%

ergy requirements for different SPF drying scenarios in a typical industrial kiln. One significant result of this comparison is the extremely large amount of energy required to dry balsam fir as compared to drying either spruce or pine. This is a direct result of both the very high initial MC for this species and the long drying time required.

Table 20-2

Estimated energy consumption when kiln drying SPF in a 250 MBM capacity, direct-fired, heat-and-vent kiln to a final MC of approximately 17%. Estimates are based on average annual climatic conditions.

Species	Initial MC (approx.)	Approximate Drying Time		Thermal Energy Requirement	
		Hrs	million btu/MBM*	GJ/m ³	
SPF (combined)**	53	42	1.15	0.67	
Black spruce	77	45	1.75	1.02	
White spruce	59	38	1.19	0.69	
Jack pine	51	31	1.17	0.68	
Lodgepole pine	50	38	1.12	0.65	
Balsam fir	118	82	2.36	1.38	
Subalpine fir	65	58	1.26	0.73	

* MBM nominal lumber volume, m³ actual lumber volume

**70% lodgepole pine, 20% white spruce, 10% subalpine fir

These energy estimates are based on the net amount of energy delivered to the kiln and do not take into account efficiency factors related to the energy system. They are also all based on good drying practices, with the kiln equipment in good condition, and dried to the appropriate final MC. The following sections deal with different aspects of the kilns' operation and how each can affect energy consumption.

20.4 OPPORTUNITIES TO REDUCE THERMAL ENERGY DEMANDS

Some of the suggestions listed above are useful when considering options to install a new kiln, but what about existing kilns? When dealing with an energy guzzling, less-efficient type of kiln what can be done to reduce energy costs? The best investment can only be determined on a case by case basis, but the following guidelines may be helpful.

1. Repair a leaky kiln if there is trouble maintaining kiln conditions or a lot of steam or water spray is being used to maintain the wet-bulb temperature.

- As a basic rule, look into improving kiln insulation if drying times are very long.
- Heat losses through the kiln vents can be reduced by using air-to-air heat exchangers to preheat the incoming air.
- Avoid over-drying the lumber. Raising the final MC by even a small amount will have a significant effect on both drying time and energy consumption.
- Consider pre-sorting material to supply a more uniform product to the kiln and thereby reduce final MC variability.
- Take measures to improve uniformity of temperature and airflow in the kiln. A more uniform drying environment will result in a more uniform final MC and this may result in a shorter drying time or eliminate the need for an equalization treatment.
- Consider air drying to reduce initial MC going into the kiln. Many species can tolerate air drying and free water can be driven off quite readily – even in a cold climate!

Further detail and explanation on each of the above points is provided in the following sections.

20.4.1 VENTING LOSSES

In a heat-and-vent kiln venting is a necessary part of the process. Recapturing some of this energy is covered in a later section. This section deals with the situation that exists in many mills of uncontrolled or over-venting. The normal process for venting can be referred to as controlled venting and involves opening flaps, normally on the roof of the kiln, to exhaust warm humid air and bring in relatively cool dry air.

Uncontrolled venting refers to the flow of fresh air into the kiln other than through the kiln vents, and its contribution to the energy losses depends on whether drying requires venting to release the evaporated moisture. When drying requires venting to release the evaporated moisture, then the total volume of vented air (controlled plus uncontrolled) should be more or less independent of the way in which venting occurs. On the other hand, when limited venting is required, uncontrolled venting can be considered an unnecessary loss of heat and humidity.

Uncontrolled venting is usually a result of leaks around kiln panels and especially around kiln doors. Chapter 9 provides details on how to make a kiln tighter along with some of the operational advantages from doing this.

Ventilation losses depend on differences in dry- and wet-bulb temperatures inside and outside the kiln, and these losses increase proportionally with the amount of water evaporated. As a general rule, the lower the kiln dry- and wet-bulb temperatures, the higher the amount of fresh air required to ventilate the same amount of water vapour. For example, if the lumber in the earlier example is dried at a constant temperature of 185 F (85 C) with a wet-bulb depression of 25 F (14 C), the ventilation losses will be approximately 100,000 btu/MBM. If the dry-bulb temperature is reduced from 185 F (85 C) to 158 F (70 C) and the same wet-bulb depression is maintained, the ventilation losses increase to approximately 200,000 btu/MBM.

20.4.2 HEAT LOSSES THROUGH THE KILN STRUCTURE

Insulation losses in conventional drying are a consequence of heat conduction through the kiln walls, doors, roof and floor. As shown in Table 20-1, the total heat losses in drying can range from 15 to 30% of the total energy. These heat losses include losses through the concrete floor which is typically not insulated. Therefore, when installing a new kiln, one way to reduce operating costs is to consider insulating below the concrete pad. There is no practical way of applying insulation after construction but the extra cost at the time of construction should be minimal.

Heat losses through the insulation are a consequence of the difference in temperature between the inside and outside of the kiln, and they increase proportionally to the drying time. The exterior surface area of a typical industrial kiln represents about 86 ft² (8 m²) of surface area per MBM of kiln capacity. The average insulation coefficient of both a typical fibreglass-aluminum panel construction and concrete floor will be around 4 btu/hr•m²•°C. Therefore, if the lumber in the example is dried in 3 days, then total heat loss through the kiln walls, roof, and floor is approximately 160,000 btu/MBM. If the same lumber is dried in 11 days, the energy losses through the insulation increase to 600,000 btu/MBM. Therefore, shortening drying time does have an impact on total energy consumption.

The walls, doors and roof of most kilns in Canada are composed of a semi-rigid foam or fibreglass insulation sheathed with thin gauge aluminum. The insulating value of this combination depends on the thickness of insulation used. Most common insulating materials are rated on the basis of R-value. The R-value is directly related to the rate of heat transfer per unit area with an

R-value of 1 equalling 1 ft²•F•h/btu. Most wall and roof structures are 3 to 4 inches (7.5 to 10 cm) thick with a total R-value of up to 20. R-values will vary depending on the type and density of insulating material used. Semi-rigid fibreglass has a R-value of from 3 to 5 per inch of thickness. Some kiln doors are as thin as 2 inches (5 cm). Thin kiln doors not only contribute to extra heat loss from a lower insulating value but they are also more susceptible to damage during opening and closing and as a result are more likely to have problems with air leakage. These factors often combine to produce "cold" zones near the end of long, track-loading kilns.

Increasing the amount of insulation on a kiln will reduce heat losses and overall energy requirements. What needs to be considered is whether or not an investment in insulation will result in a good return on the investment. The specific answer to this question will depend on many site-specific parameters including source and cost of energy. The following example should help determine the expected reduction in energy consumption due to adding insulation. This can be combined with energy cost data to determine the payback.

EXAMPLE:

- Track kiln:
 - 120 ft. (36 m) long
 - 18 ft. (5.5 m) high
 - 30 ft. (9 m) wide
- Drying at temperatures: Up to 200 F (93 C)
- Average R-value of kiln walls, doors, and roof (pre-upgrade) = 15
- Average R-value after upgrading insulation = 30
- Total expected annual energy savings = 363 million btu
- Approx. fuel equivalent = 10,000 m³ natural gas

OR 9,800 litres of No. 2 fuel

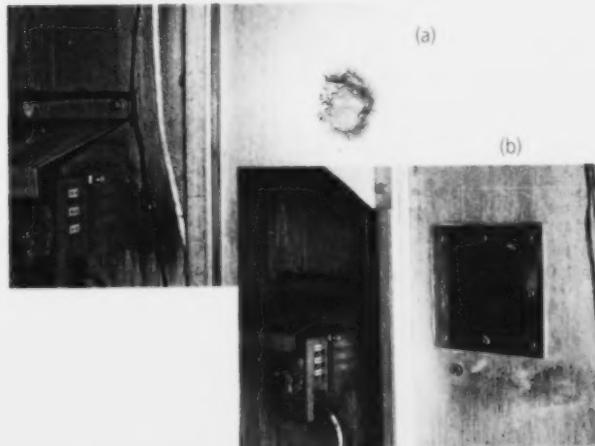
The above example would help a mill determine the direct payback from installing extra insulation on a kiln. The direct payback will be the result of a reduction in the amount of fuel used and the cost of that fuel will determine the attractiveness of the investment. There are, however, other indirect benefits which will result from installing extra insulation. As mentioned above, a tighter kiln will produce a more uniform drying environment which will, in turn, produce a more uniform final MC. Even small reductions in energy requirements will sometimes be enough to eliminate bottlenecks at the energy system. This could mean being able to more easily meet peak demands or being able to supply heat to

other applications. In some instances this could even help avoid the need to either expand or replace the existing energy system.

Another consideration with regard to kiln insulation is whether or not the existing insulation is performing up to its rating. Corrosion, deterioration of sealing material and physical damage to panels are all reasons why moisture may have found its way into the wall cavities and reduced the effectiveness of the existing insulation. There are several ways to check for this. When the kiln is operating you can check for "hot spots" on the outside of the kiln with a contact surface temperature sensor, an infra-red thermometer to obtain remote readings, or simply use your hand. Hot spots in a kiln panel may indicate that the insulation has become saturated with water. The next step would be to cut or drill a small inspection hole to feel the insulation. If the insulation is found to have deteriorated, the next step should be to consider the options to replace it and repair the problem that allowed the situation to develop.

Figure 20-1

An inspection hole can be cut into a kiln panel or an existing hole (a) used to check on the condition of kiln insulation. In either case the hole should be properly patched and sealed (b) to avoid further infiltration of moisture into the walls.



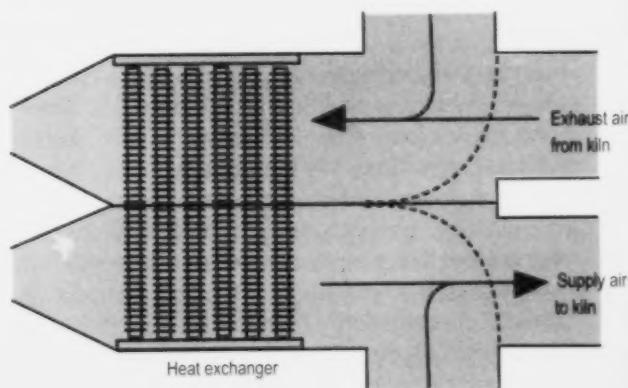
20.4.3 HEAT EXCHANGERS TO RECOVER VENTING LOSSES

In a traditional heat-and-vent kiln, all the heat used to evaporate water from the wood is lost. If the kiln is in good condition, most of this lost energy will be exhausted in the form of warm moist air through the vents. Therefore, there exists an opportunity to capture that heat and re-use it to make the entire process more energy efficient.

Vent losses can be reduced by installing air-to-air heat exchangers to warm up the incoming fresh air with heat from the kiln exhaust air. Figure 20-2 illustrates the principle of an air-to-air heat exchanger. The incoming fresh air from outside is heated with hot air flowing out of the kiln by indirect contact through a heat exchange surface.

Figure 20-2

An air-to-air heat exchanger can be used to recapture heat from exhaust air and pre-heat incoming air.



The maximum amount of energy that can be recovered with an air-to-air heat exchanger is the heat required to warm up the fresh air from the outside temperature to the operating temperature of the kiln. This value corresponds to the kiln vent losses (Item No. 6 in Table 20-1) and can vary from 10 to 25% of the total energy requirements. The energy in the exiting air stream represents the energy used to heat and evaporate moisture in the wood (Item No. 4 in Table 20-1) and can vary from 50 to 70% of the total energy requirements. Therefore, even with an efficient heat exchanger, there is a limit to how much energy can be re-used in the process. In tests conducted on a research-scale kiln at Forintek, a heat-pipe type of heat exchanger was able to consistently raise the temperature of the incoming air to within 10 F (5.5 C) of the operating temperature of the kiln.

After heating the incoming air, there will still be considerable energy left over in the exiting air stream. This warm moist air could potentially be passed through another heat exchange system to serve some other heating need such as pre-heating boiler water or assisting with space heating requirements. Air leakage and air required for

combustion in direct-fired kilns are other factors reducing the potential efficiency of a heat exchange system.

The use of air-to-air heat exchangers has been considered for decades but the overall economics have not been attractive enough to generate widespread acceptance. As with the idea of installing extra insulation the economic feasibility will depend largely on the type and cost of fuel being used. Other factors which can potentially motivate a mill to consider this technology are the idea of freeing up more energy to fire an additional kiln or avoiding problems with meeting peak demand. These situations are more likely to develop in larger mills with multiple kilns.

There are many different types of heat exchange technologies used in many different industries. For lumber drying applications, air-to-air heat exchangers are the preferred technology. Within air-to-air exchangers there are two main types which have been employed in dry kilns and they are plate type and heat pipe. In both types there is the potential to reduce the temperature of the outgoing air stream to below the dew point resulting in condensation. Therefore, there is a need to design these systems to drain any condensate that forms and to periodically inspect and clean the heat exchange surfaces.

20.4.4 REDUCE OVER-DRYING

In an industrial kiln holding 200 MBM of lumber, over-drying by only 1% MC will result in having to remove the equivalent of approximately 4,300 gallons (19,500 litres) of additional water per charge. Considering the various efficiency factors involved in industrial drying, this small amount of over-drying in the above kiln would result in an extra fuel requirement of approximately 30,400 m³ of natural gas per year or 29,800 litres of No. 2 fuel oil. At a rate of \$8.00/ m³ for natural gas this would amount to an additional fuel cost of approximately \$240,000 per year just for the one kiln. Even for mills relying on wood residue as their fuel source, this reduction in energy will have benefits in terms of better utilization of the energy system and reduced environmental impact.

All of the above is based on over-drying by only 1% MC. Considering some drying operations may be over-drying by 3 to 4% MC or more, the opportunity to reduce operating costs and increase energy efficiency are even more significant. The main reason for over-drying is the necessity to get average final MC to the right level. When a wide range of final MC exists, the average must be reduced further in order to achieve the appropriate por-

tion of material above the highest acceptable limit (usually no more than 5% of a load above 19% MC for SPF dimension lumber). Therefore, the best way to raise the final average MC is to address the factors that contribute to final MC variability. Many of the topics discussed in this manual are designed to achieve just this. This would include, schedule modification, better equipment maintenance, and better selection and preparation of material for kiln loads. It could also include installing capacity to run on slower drying schedules or the ability to conduct equalization treatments. More drastic measures that achieve this same objective include the options of pre-sorting or implementing a re-drying program. Information on both of these concepts is presented in earlier chapters.

20.4.5 AIR DRYING

Air drying can be considered as free drying when it comes to energy costs and kiln residence time. Any reduction in initial MC will result in energy savings. As shown in the example in the section on over-drying even small changes in the amount of moisture that needs to be dried in the kiln will have a significant impact on energy consumption. If, for example, the initial MC of balsam fir is reduced from an average of 100% to 50% through air drying, the energy savings at the kiln would be approximately 50 times higher than that demonstrated in the over-drying example. For the same 200 MBM capacity kiln dedicated to drying balsam fir, the energy saving would therefore be approximately 1.5 million m³ of natural gas per year. Proper techniques and other benefits associated with air drying are covered in Chapter 13.

20.5 IMPACT OF KILN DESIGN

The choice of dry kiln has a very significant impact on the amount of energy used to dry lumber.

20.5.1 DIRECT-FIRED KILNS

In many systems the products of fuel combustion are released directly into the kiln. These kilns are normally referred to as direct-fired, and they are very efficient in terms of energy utilization. In direct-fired kilns, hot gases of combustion go directly into an air duct where air from inside the kiln is taken, mixed with the hot gases, and re-distributed inside the kiln. The temperature of combustion will be approximately 1100°C (approx. 2000°F), but the hot gases are diluted in the air duct to temperatures that are safe for the kiln and lumber. This "cooled" air is then mixed with the air in the kiln to achieve the desired temperature. The main energy loss in a direct-fired energy system is thermal radiation from the burner and

duct surfaces; this is typically less than 5% of the total energy consumed.

One limitation of direct-fired kilns is that they cannot reach high wet-bulb temperatures. Although combustion of fossil fuels or wood residue produces water, this is only sufficient to achieve wet-bulb temperatures of about 50 to 55°C (122 to 131°F). The rest of the water vapour required to reach the desired wet-bulb temperature must be provided by other means. This can include moisture evaporated from the wood or the injection of water vapour in the form of steam or water mist. Injecting water into the hot air stream may help raise the wet-bulb temperature but it will also contribute to higher energy consumption, as energy is needed to evaporate this moisture.

Another limitation of direct-fired kilns is that they typically operate with a higher internal air pressure than other heating systems. This contributes to greater overall leakage of kiln air, especially around the doors. This leakage can contribute to higher heat losses from the system. Also, the water vapour leaking around the kiln doors will quickly condense on the door and door frame which may lead to more problems with corrosion in these areas.

Figure 20-3

Keeping doors and gaskets in good condition will help minimize losses of heat and humidity and help achieve the prescribed kiln conditions.



20.5.2 INDIRECT-HEATED KILNS

Indirect-heated kilns are those equipped with an energy system where the products of combustion are used to heat up a thermal-fluid such as steam, water or oil that flows inside a heat exchanger. The hot thermal-fluid is then pumped to other places in the mill where heat is required. Since heat can only flow from hot to cold, burner gases will still be hotter than the thermal-fluid when they are released from the burner stack. For example, thermal oil being returned from the kiln may need to be heated to about 480°F (250°C) and in such

a case the gases discharged from the stack will still be around 570°F (300°C). Hot water, indirect-fired systems and steam boilers require much lower temperatures, and gases from the stack may discharge at around 360°F (180°C). The greater the temperature difference between the burner gases and the heating medium, the more efficient the overall system will be.

A modern boiler, in good condition producing steam from natural gas or oil is 85 to 90% efficient. This means that of the fuel burned only 85 to 90% of the total btu value is actually captured in the steam. There are further losses in these systems due to heat transmission along pipes leading to the kilns. If a boiler is employed it should be well maintained to ensure that it is operating as close as possible to the maximum energy efficiency. Steam pipes from the boiler to the kiln should be as short as possible and well insulated to minimize heat losses. Steam traps and other components of the heat transfer system must also be in good working order to extract the most from the steam being supplied to the kiln. Poorly designed and/or maintained steam systems are a common cause of heating problems and energy inefficiency in kilns.

20.5.3 DEHUMIDIFICATION KILNS

Dehumidification (DH) kilns offer the opportunity to reduce the "bottom line" in terms of energy consumption. They do this by recapturing and reusing some of the energy used to evaporate moisture from the wood. DH kilns use a compressor and refrigerant system and operate as a heat pump. Moisture evaporated from the wood is condensed on a cold coil containing refrigerant gas, and the refrigerant gas is compressed and condensed inside a hot coil to return the heat of evaporation to the kiln air as "dry heat". If everything is engineered and designed correctly, these systems can operate as a closed loop with no, or very little, venting required. In this manner, these kilns can be built much tighter and are usually better insulated than heat-and-vent kilns.

DH may only require 50% or less of the energy required to dry in a heat-and-vent kiln. The process is most efficient during the early stages of drying while the wood is still above the fibre saturation point (FSP=25 to 30% MC). As a result, some manufacturers have offered a "hybrid" kiln that utilizes DH technology for the initial drying phase and converts to a conventional heat-and-vent mode of operation when the wood is below the FSP. Whether or not the energy savings associated with a DH kiln translate into a cost saving depends on a lot of factors specific to each installation. Local energy op-

tions and costs must be considered along with final MC requirements.

20.6 ELECTRICAL ENERGY REQUIREMENTS

The main use of electrical power in heat-and-vent kilns is to power the motors that drive the fan system. Electrical energy demand at the kiln will represent about 5% of the total energy requirements for drying. Since electricity is usually the most expensive form of energy used in drying, this 5% can translate into a much bigger proportion of the total energy cost.

Air flow has long been an underrated factor in the drying of SPF lumber. It is only recently that the contribution of airflow to overall drying rate and MC uniformity has been recognized. Specific recommendations on airflow requirements are provided in Chapter 15. As equipment manufacturers and operators implement faster and faster rates of airflow, the need to consider ways and means of achieving greater energy efficiency becomes more pressing.

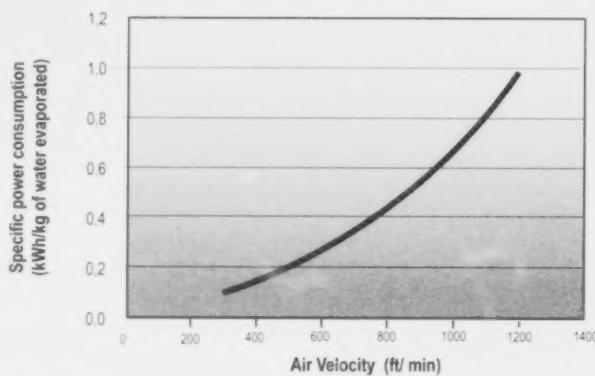
20.6.1 ENERGY SAVINGS FROM VARIABLE SPEED DRIVES

High airflow has been shown by numerous authors, including work done at Forintek, to be beneficial in increasing the drying rate above the FSP. Figure 6-5 (Chapter 6) shows the impact of airflow on drying rate when drying SPF. Given that there is no benefit to higher airflow below 25 to 30% MC it makes sense to consider installing technology to reduce airflow at this stage in drying. This is even more attractive when considering that energy requirements of an electric motor and fan assembly increase as a cube of the fan speed. That is, if the fan speed is reduced by one-half it can be expected that the energy consumption will be reduced to about 1/8 of the previous level. The other implication of this is that even small reductions in fan speed can have a significant impact on electrical energy requirements. Even reducing the airflow by about 20% will cut elec-

trical energy consumption in half. Figure 20-4 shows how energy consumption increases as a function of airflow and reinforces the benefits associated with fan speed reduction.

Figure 20-4

Electrical energy requirements of fans as a function of airflow.



An earlier Forintek study demonstrated energy savings resulting from reducing fan speed during high-temperature drying of jack pine and spruce. The strategy employed in this case was to reduce fan speed as temperature drop across the load (TDAL) decreased. Since TDAL is strongly affected by wood MC this achieves the same goal outlined above – to reduce fan speed as MC is reduced. In this case a variable speed drive was used to modify fan speed at various stages in drying. The fan speed adjustments achieved a 50% reduction in electrical energy consumption with no impact on drying time, product quality or final MC distribution.

Variable speed drives offer one way to reduce fan speed during drying. The payback on a system will depend on local electrical rates and the extent to which airflow can be reduced.

EXAMPLE

Species being dried:

Kiln capacity:

Maximum drying temperature:

Total installed fan horsepower:

Airflow – at full speed:

Reduced airflow (below FSP):

Drying time:

Portion of drying cycle below FSP:

Mix of black and white spruce and jack pine

288 MBM

Approx. 210°F (98°C)

260 HP

1000 fpm (5.1 m/s)

500 fpm (2.5 m/s)

Approx. 30 hrs

60% of total drying time

Payback period for an adjustable speed drive:

12.6 months

In order to achieve savings from reducing airflow, a kiln must already be running with airflow somewhat in excess of the minimum requirements. The absolute minimum recommended airflow for any kiln is approximately 300 fpm (1.5 m/s). Any kiln operating below or near this level should not even be considered for an adjustable speed drive. For SPF it is suggested that only those kilns operating with an average airflow in excess of 500 fpm be considered for an adjustable speed drive.

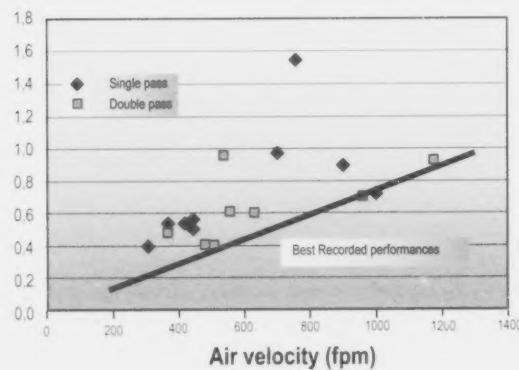
Most mills realize benefits from installing an adjustable speed drive beyond the energy savings. The ability to ramp up the speed slowly at the start of drying reduces peak demand and extends motor life. The fan system can also be designed to operate at its peak efficiency only once the kiln has warmed up. This provides the opportunity to either get more out of existing motors or to specify a slightly smaller motor when designing a new kiln.

20.6.2 EFFICIENCY OF AIRFLOW SYSTEM

Most mill operators have paid very little attention to specific details of the fan system when purchasing a kiln. In most cases this is not a detail that is considered much beyond specifying what the target airflow is and the cost of the system. Some recent work, however, has shown that there is a wide range in energy efficiency of airflow systems between one kiln and another. Figure 20-5 shows a comparison of installed horsepower versus average airflow as measured in a number of industrial dry kilns. The various combinations of fan type, fan drive system (line vs. cross-shaft) and kiln configuration (track- vs. package-loading) along with other factors will result in a wide range of efficiencies. Forintek work has shown that getting the best combination of technology can reduce electrical energy demand by up to 35%.

Figure 20-5

Airflow efficiency as a factor of installed horsepower versus air flow rate achieved. Results of survey of industrial drying operations.

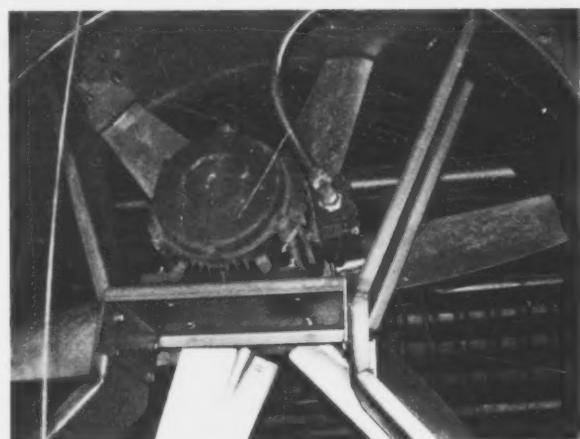


Some characteristics that go toward making a fan system more efficient include:

- adequate plenum width in kiln and no constrictions in the airflow path from the fans to the lumber
- well-piled lumber on appropriately-sized stickers (usually $\frac{3}{4}$ -inch thickness)
- maintaining a chimney space between adjacent packages in the kiln
- well-baffled loads to minimize bypass air
- fan motors, fan and fan pitch matched to achieve maximum efficiency
- using a variable speed drive to reduce fan speed whenever possible.

Figure 20-6

There are many ways to get more airflow from existing equipment, including optimizing the fan blade angle and adding well-placed deflectors and baffles.



NOTES

COST CONSIDERATIONS IN DRYING

21.1 OVERVIEW

In business everything eventually comes back to cost versus benefit. The purpose of drying is to bring the lumber to a condition that will ensure that it performs better in service. For most applications, wood could not even be considered unless it was properly dried. Regardless of this, when most mill operators look at an existing or proposed drying operation they want to know what direct return they will have on their investment. Drying wood increases its value and this increase in value must more than offset the costs associated with drying. In order to make good decisions on equipment or operating strategies it is important to have good information at hand on the real costs of drying. Given the variability of most costs, and especially energy costs, it is not practical to try to quantify actual drying costs in this type of manual. Therefore, this chapter will deal with identifying the various components of the overall drying cost. This will help mill or kiln operators conduct their own review of the actual or expected economic performance of a drying operation.

In general, anything being done as a result of drying that would not be done if the lumber was sold green, should be considered as part of the drying cost. However, over and above this, there is another element that does not often get considered as part of the drying cost. Drying degrade is a reduction in the potential value of the lumber. Although a certain amount of degrade is inevitable in drying, the differences in drying degrade between one drying system and another or even between one drying schedule and another should be considered when making decisions on equipment type or capacity.

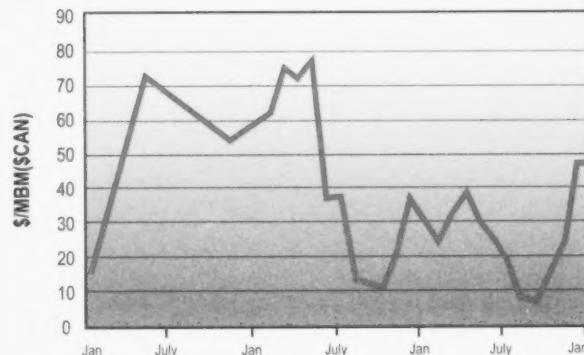
21.2 REVENUE FROM DRYING

The first component to consider when evaluating the economics of a drying installation is the revenue portion. Revenue generated from drying is quite erratic, more so even than lumber prices themselves. The graph in Figure 21-1 shows how price differential between green and dry can vary considerably. In this case over just a two-

year period the price differential varied from less than \$10/MBM to over \$70/MBM. Since these price differentials are often used to help justify investments in kilns or kiln additions, it is important to consider the longer term average rather than spot prices. There is not much likelihood that anyone could justify installing kilns, strictly from the point of view of return on investment if the price differential remained consistently below \$10/MBM. By the same token, it would be unwise to base an investment decision on the highest price differential.

Figure 21-1

Price differential between green and dry 2x4 lumber over a two-year period.



There are several factors other than price differential which motivate mills to dry lumber. Dry lumber is a much more stable product to ship and store than green material. Also, due to the larger market for dry lumber, there are more options of where it can be sold, providing more flexibility. Dry lumber is the commodity in the marketplace. For most mills, green lumber is just a point along the production chain. Therefore, when making major investment decisions, rather than considering the drying operations on their own, it may make more sense to look at the total production cost at the sawmill site rather than individual steps within the processing chain. This does not mean that there should no concern with

detailed costs at the kilns. Information on profitability at the kilns will help identify payback on equipment additions or changes to the manufacturing process.

21.3 COST OF DRYING LUMBER

The short answer to the cost of drying lumber is to consider everything that needs to be done (or done differently) than if the lumber were sold green. For the most part this involves things taking place from the outfeed of the sawmill to the infeed of the planer mill. In some cases there may be activities beyond this that need to be considered as part of the drying cost. For example, if pre-sorting is being done to improve final product quality or productivity at the kilns it may be considered as part of the overall drying cost. As mentioned in the previous section, however, it is not always reasonable to look at all of the drying costs and expect that they will all be offset by the difference in dry versus green lumber alone.

Drying costs can be categorized as:

- capital, or upfront costs
- fixed costs and
- variable costs.

The following sections provide an overview of the main components within each of these groups. This is not intended to be a comprehensive list. Anyone wishing to conduct a detailed economic analysis of a drying operation (or proposed drying operation) is encouraged to check some of the references provided in the section on further reading.

21.3.1 CAPITAL COSTS

Capital cost is often the cost component that is most closely scrutinized by potential buyers of kilns. This is reasonable given that a kiln is a major purchase for any company; however, it is important to make sure that the equipment selected will do the job. Cutting corners at the equipment selection stage may potentially affect productivity and or quality outturn. Although saving a small amount on up-front costs may seem attractive, the cost of operating a less productive system or system that cannot produce the required quality will remain long after the initial sale.

An important part of obtaining capital cost estimates is to set specific operational targets that need to be met and then making sure that quotes received are for equipment that can meet these targets. Information provided in earlier chapters on kiln performance (Chapters 7, 8 and 9) will help set performance specifications for kilns or kiln components. Sizing the kiln is another impor-

tant aspect. Some guidance on how to determine the required kiln size is provided in a later section of this chapter.

Capital cost usually includes all of the purchases that need to be made up-front to make an installation operable. A typical drying installation for a mill with no existing kilns may include the following:

- dry kiln(s)
- cost to acquire or prepare land
- control room
- energy system
- kiln carts (track kilns)
- dry storage area or roof over dry end of kilns
- lumber piling equipment
- extra forklift(s) for loading and unloading
- unstacker and sticker recovery equipment
- initial supply of stickers
- setup of both green and dry storage areas in mill yard
- kiln test equipment (i.e., temperature monitoring, MC meters, etc.).

21.3.2 OPERATING COSTS

Any cost incurred as a result of operating a drying facility is considered an operating cost. Some of these costs are constant regardless of production level, "Fixed Costs", whereas others are directly tied to the production from the kilns, "Variable Costs". Examples of both cost types are listed in the following sections.

21.3.2.1 FIXED COSTS

Fixed costs are those that remain constant, or close to constant, regardless of production level at the kilns. Some of these may be considered as overhead items (things that are done in support of the drying operation) while others may be more directly related to the day-to-day operation. These costs are usually calculated as a lump sum on an annual basis. Some examples of fixed operating costs include:

- management costs
- taxes
- Insurance
- equipment maintenance
- depreciation
- kiln supervision (may be partly variable).

21.3.2.2 VARIABLE COSTS

Variable costs are those that fluctuate with the level of production. Some costs, such as kiln supervision may be partly variable and partly fixed. For example, the primary kiln operator will often be assigned only to the kilns and does not shift around with changes in material flow. Secondary supervisors or kiln loading personnel will often only work at the kilns on an "as needed" basis and therefore their cost can be considered variable. These costs are usually calculated on the basis of cost per unit volume of production (i.e., \$/MBM). The following items can all be considered as variable costs.

- Energy
 - thermal energy (fossil fuel, wood residue, etc.)
 - electricity (for kiln fans and energy system)
- Labour
 - kiln supervision and operation
 - kiln loading
 - lumber piling
- Loaders and loader operators
- Re-supply of stickers (replenish breakage)
- Strapping costs.

Another variable cost of drying is the degrade that occurs as a consequence of drying. This is often an over looked component but is important in determining the success or failure of a drying operation.

21.3.2.3 COST OF DRYING DEGRADE

Many people consider drying degrade as a natural consequence of drying wood. The development of, and factors contributing to, drying degrade are well covered in earlier chapters. It should be clear by this point that a certain portion of drying degrade is unavoidable. Another portion of drying degrade may be avoidable but the measures needed to minimize or avoid it have some cost associated with them. In order to make a judgment of whether those costs are warranted, it is important to have a good estimate of the level of drying degrade and the possible impact of implementing a certain action. For example, running a longer drying schedule may reduce final MC variability and reduce over-drying but the gain in grade outturn must be offset against the reduced productive capacity at the kilns. As another example, not installing a humidification system will reduce capital costs but may have the impact of increasing operating costs by over-drying and downgrading a larger proportion of boards. Therefore getting a handle on the relative difference between one scenario and another is often what is required to determine the payback and feasibility of an investment.

Figure 21-2

Drying degrade should be considered as a cost of drying. Efforts to reduce the "avoidable" portion of warp will pay off in improved grade recovery.



Drying degrade is one of the most difficult components of operating costs to estimate. It will vary not only with the type of equipment chosen and the way it is operated but also, to a large extent, with the characteristics of the material being dried. Even a single species may vary considerably across its range making degrade experiences or expectations at one mill not relevant to another. The only solution is to put in place systems to measure drying degrade. Some ways and means of doing this are presented in Chapter 18 on Quality Control.

Once a good target level of accepted drying degrade has been developed, measured and achieved, it then becomes possible to make changes to the process and measure their impact. Changing a drying schedule or the pre-sorting criteria may result in better productivity

at the kilns but the gains made there may be offset, in part or in whole, by increases in drying degrade.

Since resource characteristics can change from season to season (and even week to week) at a given mill, it is important to make and measure the impact of changes when the log mix going into the sawmill is relatively stable. If, for example, the proportion of balsam fir in the lumber mix increases at the same time that a change is made in the drying schedule it will be impossible to get a true measure of the impact.

21.4 DETERMINING KILN CAPACITY

Chapters 7 and 8 provide some information on determining equipment capacities in terms of moisture extraction, airflow, etc. When conducting an economic analysis it is important that the kilns considered all have the technical capability to dry the material properly. It is also important that the kilns being considered are sized correctly to realistically handle the volume of wood to be dried each year. The most important variable to quantify is the expected drying time associated with each kiln

system considered. All the costs identified above have an impact on the economic viability of a kiln facility but when a feasibility analysis is conducted, it is variations in the production level from the kilns that will have the biggest impact on the outcome.

The net drying time for a given species and thickness of material is the per charge drying time without taking into account equipment breakdowns or time to load and unload the kiln. The best estimates of net drying time are those from other parts of your own operation or other, nearby mills drying a very similar product. Drying times will inevitably vary from summer to winter so the best estimate of net drying time is a weighted average value for the year. The net drying time must be adjusted for turnaround time from charge to charge. This, in turn, will be influenced by the kiln configuration (track- vs. package-loading) selected. Finally, some allowance needs to be made for regular maintenance and (in some cases) an annual shutdown for holidays and/or major maintenance. The following provides an example of the manner in which to determine the required kiln capacity for a given annual production.

SAMPLE KILN CAPACITY DETERMINATION

• Required production:	50,000 MBM/yr.
• Species:	Black spruce
• Dimensions:	2x4 & 2x6
• Weighted average net drying time:	46 hours
• Kiln loading/unloading time:	2 hours/charge
• Total cycle time:	48 hours
• Maximum operating hours/yr:	365x24 = 8760 hours
• Deduct 1 week for annual shutdown:	168 hours
• Downtime for repairs and maintenance:	172 hours (2% of operating hours)
• Total hours available for drying:	8,420 hours/yr.
• No. of drying cycles per year per kiln:	8,420/48 = 175 cycles/kiln
• Total kiln capacity required per charge:	50,000 MBM/175 cycles = 285 MBM

Therefore a single kiln (or combination of kilns) with a total lumber holding capacity of 285 MBM would be required to dry the stated production target under the above conditions.

Another factor that affects capital cost is the manner in which the required kiln capacity is broken up. For the example above, some companies may elect to go with a single 285 MBM capacity dry kiln while others may find it advantageous to break this up to 2 or 3 smaller kilns. This should be determined at the outset as there are obvious implications with regard to the capital cost estimates. A stud mill may be content with a single kiln chamber whereas a dimension lumber mill producing many different products and sizes will benefit from having several smaller chambers.

21.5 ECONOMIC PERFORMANCE

Economic performance of an investment can be expressed as payback period, return on investment, net present value, or other similar parameters. For relatively small investments, a simple payback period can be calculated by determining how long it will take to recover the initial investment. For example, if an investment of \$10,000 in an energy saving technology results in annual savings of \$20,000 in fuel the simple payback will be 6 months. In this case, probably nothing further would be required to make a decision on the investment.

When the investment is larger, more complicated, or less obvious than the above example, more detailed information is needed. Most large investments must be considered over a longer time span and sometimes even over the expected life of the equipment in order to make a sound decision. There are many cash flow analysis programs and professional economists that can be utilized for this purpose. What these programs and specialists cannot provide is the detailed information on the actual or expected costs. This is where the kiln operator and other mill staff must get involved and ensure that the information provided is as accurate as possible.

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TEMPERATURE CONVERSION

To use these tables find the 10s digit for the temperature to be converted in the left hand column and then find the intersection of that line with the 1s digit along the top line.

The value in the intersecting point is the converted temperature rounded to the nearest degree.

DEGREES C TO DEGREES F (ROUNDED TO NEAREST DEGREE)

(example for 65°C to 149°F)

	0	1	2	3	4	5	6	7	8	9
-20	-4	-6	-8	-9	-11	-13	-15	-17	-18	-20
-10	14	12	10	9	7	5	3	1	0	-2
0	32	34	36	37	39	41	43	45	46	48
10	50	52	54	55	57	59	61	63	64	66
20	68	70	72	73	75	77	79	81	82	84
30	86	88	90	91	93	95	97	99	100	102
40	104	106	108	109	111	113	115	117	118	120
50	122	124	126	127	129	131	133	135	136	138
60	140	142	144	145	147	149	151	153	154	156
70	158	160	162	163	165	167	169	171	172	174
80	176	178	180	181	183	185	187	189	190	192
90	194	196	198	199	201	203	205	207	208	210
100	212	214	216	217	219	221	223	225	226	228
110	230	232	234	235	237	239	241	243	244	246
120	248	250	252	253	255	257	259	261	262	264

DEGREES F TO DEGREES C (ROUNDED TO NEAREST DEGREE)

(example for 155°F to 68°C)

	0	1	2	3	4	5	6	7	8	9
0	-18	-17	-17	-16	-16	-15	-14	-14	-13	-13
10	-12	-12	-11	-11	-10	-9	-9	-8	-8	-7
20	-7	-6	-6	-5	-4	-4	-3	-3	-2	-2
30	-1	-1	0	1	1	2	2	3	3	4
40	4	5	6	6	7	7	8	8	9	9
50	10	11	11	12	12	13	13	14	14	15
60	16	16	17	17	18	18	19	19	20	21
70	21	22	22	23	23	24	24	25	26	26
80	27	27	28	28	29	29	30	31	31	32
90	32	33	33	34	34	35	36	36	37	37
100	38	38	39	39	40	41	41	42	42	43
110	43	44	44	45	46	46	47	47	48	48
120	49	49	50	51	51	52	52	53	53	54
130	54	55	56	56	57	57	58	58	59	59
140	60	61	61	62	62	63	63	64	64	65
150	66	66	67	67	68	68	69	69	70	71
160	71	72	72	73	73	74	74	75	76	76
170	77	77	78	78	79	79	80	81	81	82
180	82	83	83	84	84	85	86	86	87	87
190	88	88	89	89	90	91	91	92	92	93
200	93	94	94	95	96	96	97	97	98	98
210	99	99	100	101	101	102	102	103	103	104
220	104	105	106	106	107	107	108	108	109	109
230	110	111	111	112	112	113	113	114	114	115
240	116	116	117	117	118	118	119	119	120	121
250	121	122	122	123	123	124	124	125	126	126

CONVERTING WET-BULB DEPRESSION

Use these tables to convert a wet-bulb depression value in one unit to the equivalent depression expressed in the other unit.

i.e., Wet-bulb depression of 5°F = 2.8°C

F° → C°		C° → F°	
1	0.6	1	1.8
2	1.1	2	3.6
3	1.7	3	5.4
4	2.2	4	7.2
5	2.8	5	9.0
6	3.3	6	10.8
7	3.9	7	12.6
8	4.4	8	14.4
9	5.0	9	16.2
10	5.6	10	18.0
12	6.7	12	21.6
14	7.8	14	25.2
16	8.9	16	28.8
18	10.0	18	32.4
20	11.1	20	36.0
25	13.9	25	45.0
30	16.7	30	54.0
35	19.4	35	63.0
40	22.2	40	72.0
45	25.0		
50	27.8		
60	33.3		

**RELATIVE HUMIDITY (RH) AND APPROXIMATE
EQUILIBRIUM MOISTURE CONTENT (EMC) OF WOOD**

Dry-Bulb (°C)	Wet-Bulb Depression (°C)																				
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	35	40	45	
5 EMC	18.9	14.0	11.1	8.9	6.8																
5 RH	86	72	59	46	33																
10 EMC	19.8	15.4	12.5	10.3	8.7	6.9	5.5	3.6	1.6												
10 RH	88	77	66	55	45	34	25	15	6												
15 EMC	20.7	16.2	13.5	11.5	9.9	8.4	7.2	5.9	4.6	3.2											
15 RH	90	80	71	62	53	44	36	28	20	13											
20 EMC	21.1	17.2	14.5	12.4	10.8	9.6	8.5	7.4	6.3	5.4	3.1										
20 RH	91	83	75	67	59	52	45	38	31	25	13										
25 EMC	21.5	17.8	14.8	12.9	11.6	10.3	9.3	8.4	7.5	6.6	5.0	3.1	0.8								
25 RH	92	85	77	70	64	57	51	45	39	33	23	13	3								
30 EMC	21.9	17.9	15.2	13.5	12.0	10.8	9.8	9.0	8.2	7.5	6.0	4.5	3.0	1.2							
30 RH	93	86	79	73	67	61	55	50	45	40	30	21	13	5							
35 EMC	21.6	18.1	15.6	13.7	12.5	11.2	10.2	9.4	8.6	8.0	6.7	5.6	4.4	3.1	1.6						
35 RH	93	87	81	75	70	64	59	54	49	45	36	28	21	14	7						
40 EMC	21.9	18.2	16.0	14.0	12.7	11.5	10.6	9.7	9.0	8.4	7.3	6.2	5.1	4.1	3.0						
40 RH	94	88	83	77	72	67	62	57	53	49	41	33	26	20	14						
45 EMC	21.5	18.4	16.1	14.3	12.9	11.7	10.9	9.9	9.3	8.7	7.5	6.5	5.7	4.8	3.8	1.5					
45 RH	94	89	84	79	74	69	65	60	56	52	44	37	31	25	19	7					
50 EMC	21.9	18.0	16.1	14.3	12.8	11.8	11.0	10.0	9.4	8.9	7.7	6.9	6.1	5.2	4.5	2.6	0.6				
50 RH	95	89	85	80	75	71	67	62	58	55	47	41	35	29	24	13	3				
55 EMC	21.5	18.1	15.7	14.3	12.8	11.8	10.9	10.1	9.6	8.9	7.9	7.1	6.3	5.6	4.9	3.2	1.6				
55 RH	95	90	85	81	76	72	68	64	61	57	50	44	38	33	28	17	8				
60 EMC	21.0	18.3	15.8	14.2	12.7	11.7	11.0	10.2	9.5	9.0	7.9	7.1	6.5	5.7	5.2	3.6	2.2	0.9			
60 RH	95	91	86	82	77	73	70	66	62	59	52	46	41	35	31	20	12	5			
65 EMC	20.5	17.8	15.8	14.2	12.9	11.8	10.9	10.1	9.5	9.0	8.0	7.1	6.5	5.9	5.2	3.9	2.6	1.4			
65 RH	95	91	87	83	79	75	71	67	64	61	54	48	43	38	33	23	15	8			
70 EMC	20.8	17.4	15.4	13.8	12.5	11.7	10.8	10.1	9.4	8.9	8.0	7.1	6.5	5.9	5.4	4.1	2.9	1.8	0.9		
70 RH	96	91	87	83	79	76	72	69	65	62	56	50	45	40	36	26	18	11	5		
75 EMC	20.3	17.5	15.4	13.7	12.4	11.6	10.6	10.0	9.4	8.7	8.0	7.1	6.5	5.9	5.4	4.1	3.1	2.1	1.2	0.5	
75 RH	96	92	88	84	80	77	73	70	67	63	58	52	47	42	38	28	20	13	8	4	
80 EMC	19.8	17.0	14.9	13.7	12.3	11.2	10.5	9.8	9.3	8.7	7.8	7.1	6.5	5.9	5.4	4.2	3.2	2.3	1.5	0.8	
80 RH	96	92	88	85	81	77	74	71	68	65	59	54	49	44	40	30	22	16	10	6	
85 EMC	19.2	16.5	14.9	13.2	12.2	11.1	10.3	9.7	9.1	8.6	7.6	6.9	6.3	5.8	5.2	4.2	3.2	2.4	1.7	1.0	
85 RH	96	92	89	85	82	78	75	72	69	66	60	55	50	46	41	32	24	18	12	8	
90 EMC	18.7	16.6	14.4	13.2	11.8	10.9	10.2	9.5	8.9	8.4	7.6	6.8	6.3	5.7	5.2	4.2	3.2	2.4	1.7	1.2	
90 RH	96	93	89	86	82	79	76	73	70	67	62	56	52	47	43	34	26	20	14	10	
95 EMC	18.1	16.0	13.9	12.7	11.7	10.8	10.0	9.3	8.7	8.2	7.4	6.7	6.1	5.6	5.1	4.0	3.2	2.4	1.8	0.1	
95 RH	96	93	89	86	83	80	77	74	71	68	63	58	53	49	45	35	28	21	16	11	
100 EMC	18.3	15.5	13.9	12.6	11.2	10.3	9.6	9.1	8.5	8.0	7.2	6.5	5.8	5.4	4.9	3.9	3.1	2.4	1.8	1.3	
100 RH	97	93	90	87	83	80	77	75	72	69	64	59	54	50	46	37	29	23	18	13	
105 EMC						10.7	9.8	9.1	8.4	8.0	7.4	6.6	5.9	5.3	4.9	4.5	3.7	3.1	2.3	1.7	1.3
105 RH						84	81	78	75	73	70	65	60	55	51	47	38	31	25	19	15
110 EMC											7.3	6.5	5.8	5.3	4.8	4.4	3.6	3.0	2.2	1.7	1.2
110 RH											71	66	61	57	53	49	40	32	26	21	16
115 EMC														5.1	4.7	4.3	3.5	2.9	2.0	1.5	1.1
115 RH														58	54	50	41	34	27	22	17
120 EMC																4.1	3.3	2.8	1.7	1.3	1.0
120 RH																51	42	35	29	23	19
125 EMC																	3.3	2.7	1.3	1.0	0.8
125 RH																	44	36	30	25	20
130 EMC																		2.5	0.8	0.6	0.5
130 RH																		37	31	26	21

Source: Based on several reports published by the US Dept. of Agriculture by W.T. Simpson et al.

**RELATIVE HUMIDITY (RH) AND APPROXIMATE
EQUILIBRIUM MOISTURE CONTENT (EMC) OF WOOD**

Dry-Bulb (°F)	Wet-Bulb Depression (°F)																						
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40	45	50	60	70	80	
40 EMC	17.6	13.0	9.9	7.4																			
40 RH	83	68	52	37																			
50 EMC	19.3	14.5	11.4	9.3	7.6	5.8	3.8	1.4															
50 RH	87	74	61	49	38	27	16	5															
60 EMC	20.2	15.5	12.8	10.8	9.1	7.7	6.3	4.7	3.2	1.3													
60 RH	89	78	68	58	48	39	30	21	13	5													
70 EMC	20.5	16.4	13.6	11.8	10.1	8.9	7.7	6.6	5.4	4.3	3.1	1.5											
70 RH	90	81	72	64	55	48	40	33	25	19	13	6											
80 EMC	20.8	16.8	14.2	12.4	11.0	9.7	8.6	7.7	6.8	5.9	4.9	4.0	3.1	2.0									
80 RH	91	83	75	68	61	54	47	41	35	29	23	18	13	8									
90 EMC	21.1	17.4	14.8	12.8	11.5	10.2	9.2	8.4	7.6	6.8	6.1	5.3	4.7	3.8	3.0	1.2							
90 RH	92	85	78	71	65	58	52	47	41	36	31	26	22	17	13	5							
100 EMC	21.4	17.4	15.1	13.0	11.9	10.7	9.6	8.8	8.1	7.4	6.8	6.2	5.6	5.0	4.4	2.9	0.9						
100 RH	93	86	80	73	68	62	56	51	46	41	37	33	29	25	21	13	4						
110 EMC	21.0	17.5	15.1	13.2	12.0	10.8	10.0	9.2	8.5	7.9	7.3	6.8	6.2	5.6	5.2	4.0	2.4	1.3					
110 RH	93	87	81	75	70	64	60	55	50	46	42	38	34	30	27	20	11	6					
120 EMC	21.2	17.6	15.1	13.4	12.1	10.8	10.1	9.3	8.6	8.1	7.5	7.1	6.5	6.1	5.6	4.7	3.2	2.5	1.1				
120 RH	94	88	82	77	72	66	62	57	53	49	45	42	38	35	31	25	16	12	5				
130 EMC	20.7	17.7	15.0	13.4	12.0	10.9	10.2	9.5	8.8	8.2	7.8	7.3	6.7	6.3	5.9	5.1	3.9	3.1	2.0				
130 RH	94	89	83	78	73	68	64	60	56	52	49	45	41	38	35	29	21	16	10				
140 EMC	20.2	17.2	15.0	13.3	12.2	11.0	10.2	9.5	8.8	8.2	7.8	7.4	6.9	6.5	6.1	5.3	4.3	3.6	2.6	1.3			
140 RH	94	89	84	79	75	70	66	62	58	54	51	48	44	41	38	32	25	20	14	7			
150 EMC	20.5	17.2	14.9	13.2	12.0	11.1	10.2	9.5	8.8	8.4	7.8	7.4	7.0	6.6	6.2	5.5	4.5	4.0	3.1	1.8			
150 RH	95	90	85	80	76	72	68	64	60	57	53	50	47	44	41	35	28	24	18	11			
160 EMC	19.9	16.7	14.8	13.0	11.9	10.9	10.1	9.3	8.8	8.2	7.8	7.4	7.0	6.6	6.2	5.5	4.7	4.0	3.4	2.2	1.0		
160 RH	95	90	86	81	77	73	69	65	62	58	55	52	49	46	43	37	31	26	21	14	6		
170 EMC	19.3	16.7	14.4	12.9	11.7	10.7	9.9	9.3	8.6	8.2	7.7	7.3	6.9	6.5	6.2	5.6	4.7	4.2	3.6	2.5	1.4		
170 RH	95	91	86	82	78	74	70	67	63	60	57	54	51	48	45	40	33	29	24	16	9		
180 EMC	19.5	16.2	14.3	12.8	11.6	10.6	9.9	9.1	8.6	8.1	7.5	7.1	6.7	6.5	6.1	5.5	4.7	4.2	3.6	2.6	1.7		
180 RH	96	91	87	83	79	75	72	68	65	62	58	55	52	50	47	42	35	31	26	19	12		
190 EMC	18.9	16.2	14.2	12.6	11.4	10.4	9.7	8.9	8.4	7.9	7.5	7.0	6.6	6.3	6.0	5.4	4.6	4.2	3.6	2.7	1.8	1.1	
190 RH	96	92	88	84	80	76	73	69	66	63	60	57	54	51	49	44	37	33	28	21	14	9	
200 EMC	18.3	15.6	13.7	12.2	10.9	10.2	9.5	8.7	8.2	7.7	7.2	6.8	6.4	6.2	5.9	5.2	4.5	4.1	3.5	2.7	1.9	1.3	
200 RH	96	92	88	84	80	77	74	70	67	64	61	58	55	53	51	45	39	35	30	23	16	11	
210 EMC	17.6	15.6	13.1	12.0	10.7	9.9	9.2	8.4	7.9	7.4	7.0	6.6	6.3	5.9	5.7	5.1	4.4	4.0	3.4	2.6	1.8	1.2	
210 RH	96	93	88	85	81	78	75	71	68	65	62	59	57	54	52	47	41	37	32	25	17	12	
220 EMC					10.3	9.4	8.6	8.0	7.4	7.0	6.7	6.4	6.0	5.6	5.3	4.6	4.2	3.7	3.4	2.7	1.8	1.3	
220 RH					82	79	76	73	70	67	63	61	58	55	54	48	43	38	34	26	19	14	
230 EMC											6.7	6.3	6.1	5.7	5.4	5.1	4.5	4.0	3.6	3.3	2.7	1.7	1.2
230 RH											68	64	62	59	57	55	50	45	40	35	28	21	15
240 EMC																4.9	4.5	3.9	3.5	3.1	2.5	1.5	1.1
240 RH																57	51	46	41	37	29	22	17
250 EMC																	3.7	3.3	3.0	2.5	1.3	0.9	
250 RH																	47	43	38	31	24	18	
260 EMC																		2.9	2.3	0.9	0.7		
260 RH																		40	32	25	20		

Source: Based on several reports published by the US Dept. of Agriculture by W.T. Simpson *et al.*

**SHRINKAGE EXPRESSED AS A PERCENTAGE OF THE
GREEN DIMENSION AND A FUNCTION OF THE FINAL
MOISTURE CONTENT**

Species	Grain Direction	Percent Shrinkage Adjusted to a Moisture Content of:					Total Shrinkage (to 0% MC)
		21	19	15	10	6	
Black spruce	Radial	1.1	1.4	1.9	2.5	3.0	3.8
	Tangential	2.1	2.7	3.7	5.0	5.9	7.5
Red spruce	Radial	1.1	1.5	2.0	2.7	3.1	4.0
	Tangential	2.3	2.9	3.9	5.3	6.2	7.9
Jack pine	Radial	1.1	1.5	2.0	2.7	3.1	4.0
	Tangential	1.7	2.2	2.9	3.9	4.6	5.9
Balsam fir	Radial	0.8	1.0	1.3	1.8	2.1	2.7
	Tangential	2.1	2.7	3.7	5.0	5.9	7.5
White spruce	Radial	0.9	1.2	1.6	2.1	2.5	3.2
	Tangential	2.0	2.5	3.5	4.6	5.4	6.9
Engelmann spruce	Radial	1.2	1.5	2.1	2.8	3.3	4.2
	Tangential	2.3	3.0	4.1	5.5	6.4	8.2
Lodgepole pine	Radial	1.3	1.7	2.3	3.1	3.7	4.7
	Tangential	1.9	2.5	3.4	4.5	5.3	6.8
Subalpine fir	Radial	0.7	0.9	1.3	1.7	2.0	2.6
	Tangential	2.1	2.7	3.7	4.9	5.8	7.4

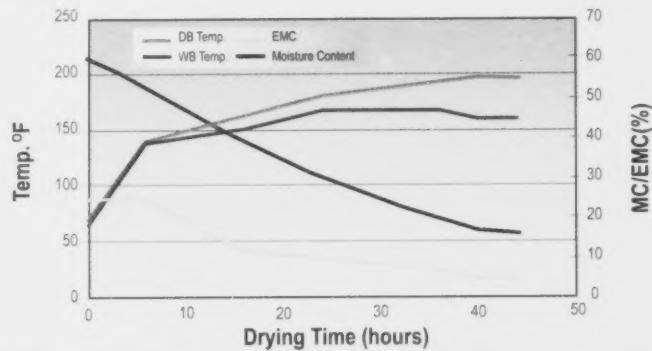
To calculate actual shrinkage for a given piece of wood use the values from the above table and the following formula:

$$\text{Actual Shrinkage} = \frac{\text{Green Dimension} \times \text{Percent Shrinkage based on final MC}}{100}$$

See Chapter 3 for further explanation on how to apply the values from the above Table and more detail on wood moisture relations.

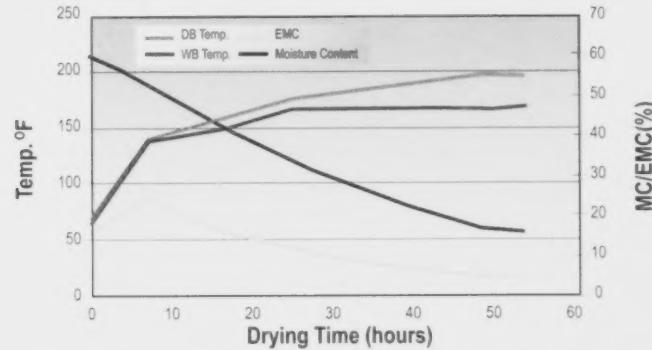
Note: See Chapter 15 for information on selection and application of drying schedules.

SCHEDULE 1



Schedule 1	Time (hrs)	6	16	24	36	42	End
	Approx MC Range	Green-55	55-40	40-30	30-24	24-20	20-end
	Dry-Bulb	140	160	180	190	195	195
	Wet-Bulb	140	150	166	166	160	160
	EMC	24.6	11.9	9.1	7	5.3	5.3
Schedule 1-A (accelerated)	Time	4	12	19	30	35	35 to end
	Dry-Bulb	140	160	180	190	195	195
	Wet-Bulb	140	148	164	164	158	158
Schedule 1-C (conservative)	Time	8	20	30	44	50	50 to end
	Dry-Bulb	140	160	180	190	195	195
	Wet-Bulb	140	152	168	168	162	162

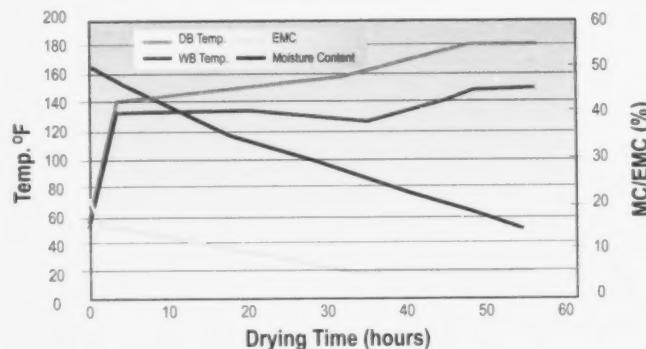
SCHEDULE 2



Schedule 2	Time (hrs)	6	16	24	36	42	End
	Approx MC Range	Green-55	55-44	44-35	35-25	25-20	20-end
	Dry-Bulb	140	160	180	190	195	195
	Wet-Bulb	140	155	172	174	168	168
	EMC	24.6	15.7	12.8	8.9	6.4	6.4
Schedule 2-A (accelerated)	Time	4	12	18	28	38	38 to end
	Dry-Bulb	140	160	180	190	195	195
	Wet-Bulb	140	153	170	172	166	166
Schedule 2-C (conservative)	Time	8	20	30	44	58	58 to end
	Dry-Bulb	140	160	180	190	195	195
	Wet-Bulb	140	156	174	176	170	170

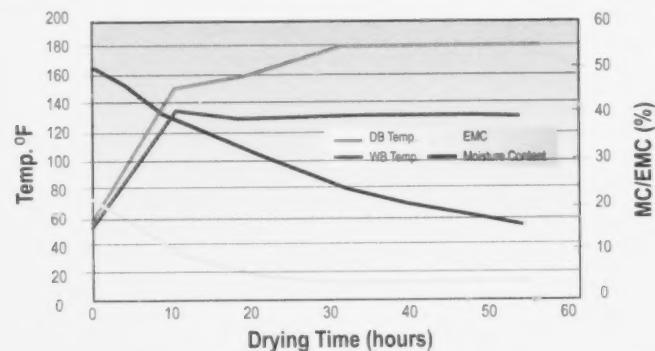
Note: See Chapter 15 for information on selection and application of drying schedules.

SCHEDULE 3



Schedule 3	Time (hrs)	2	20	32	46	End
	Approx MC Range	50-48	48-34	34-28	28-21	20-end
	Dry-Bulb	140	150	160	180	180
	Wet-Bulb	135	135	130	150	150
	EMC	16.1	9.8	6.2	6.1	6.1
Schedule 3-A (accelerated)	Time	2	18	28	40	40 to end
	Dry-Bulb	145	150	162	185	195
	Wet-Bulb	140	130	130	150	150
Schedule 3-C (conservative)	Time	4	24	36	52	50 to end
	Dry-Bulb	140	150	160	180	180
	Wet-Bulb	137	137	135	155	155

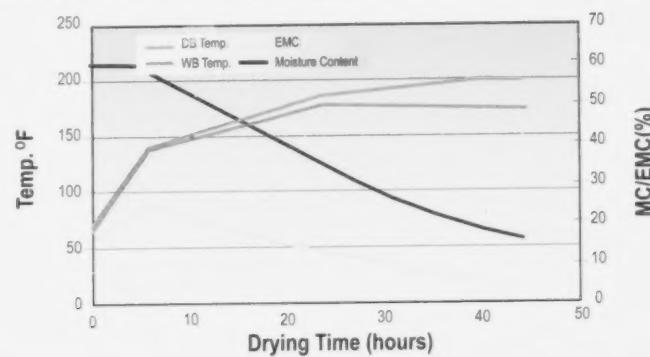
SCHEDULE 4



Schedule 4	Time (hrs)	12	20	30	End
	MC Range	Green-40	48-34	32-25	25-end
	Dry-Bulb	150	150	180	180
	Wet-Bulb	135	130	130	130
	EMC	9.8	6.2	3.6	3.6
Schedule 4-A (accelerated)	Time	10	16	24	24-end
	Dry-Bulb	150	162	190	190
	Wet-Bulb	133	130	140	140
Schedule 4-C (conservative)	Time	12	22	34	34-end
	Dry-Bulb	150	160	180	180
	Wet-Bulb	140	140	140	140

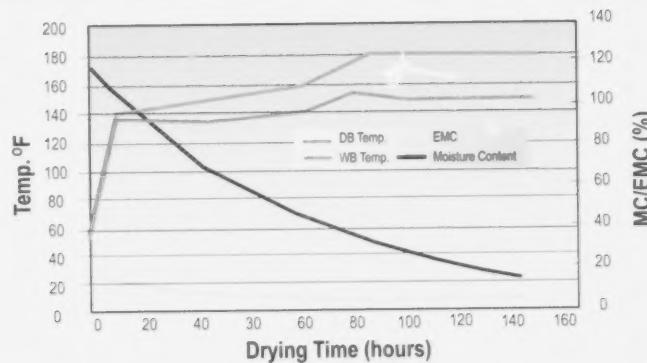
Note: See Chapter 15 for information on selection and application of drying schedules.

SCHEDULE 5



	Time (hrs)	6	16	24	36	42	42 to end
Schedule 5	Approx MC Range	Green-58	58-45	45-35	35-23	23-20	20-end
	Dry-Bulb	140	165	185	195	200	200
	Wet-Bulb	140	160	177	179	174	174
	EMC	24.6	15.6	12.7	8.8	6.4	6.4
Schedule 5-A (accelerated)	Time	4	12	19	30	36	36 to end
	Dry-Bulb	140	165	185	195	200	200
	Wet-Bulb	140	158	175	177	172	172
Schedule 5-C (conservative)	Time	8	20	29	42	50	50 to end
	Dry-Bulb	140	165	185	195	200	200
	Wet-Bulb	140	161	179	181	176	176

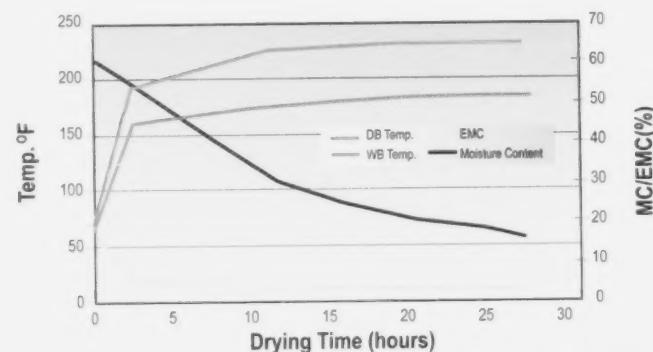
SCHEDULE 6



	Time (hrs)	4	35	60	80	100 to end
Schedule 6	Approx MC Range	120-110	110-75	75-55	55-40	40-30
	Dry-Bulb	140	150	160	180	180
	Wet-Bulb	135	135	140	155	150
	EMC	16.1	9.8	8.2	6.9	6.1
Schedule 6-A (accelerated)	Time	4	32	55	70	90 to end
	Dry-Bulb	145	150	160	180	180
	Wet-Bulb	140	133	138	150	145
Schedule 6-C (conservative)	Time	4	24	70	95	120 to end
	Dry-Bulb	140	150	160	180	180
	Wet-Bulb	135	140	145	160	160

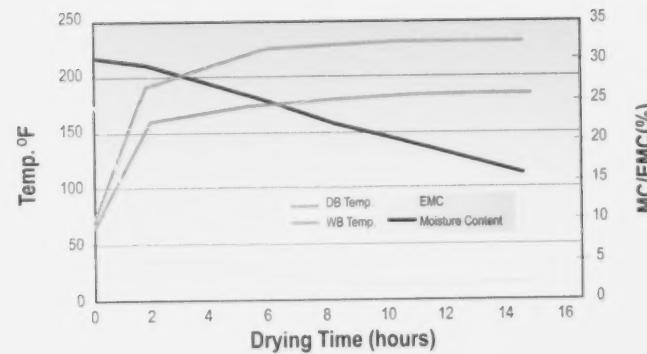
Note: See Chapter 15 for information on selection and application of drying schedules.

SCHEDULE H-1



Time (hrs)	2	10	16	End
Approx MC Range	60-55	55-40	40-24	24-end
Dry-Bulb	190	220	230	230
Wet-Bulb	160	175	180	180
EMC	6.0	3.7	3.3	3.3

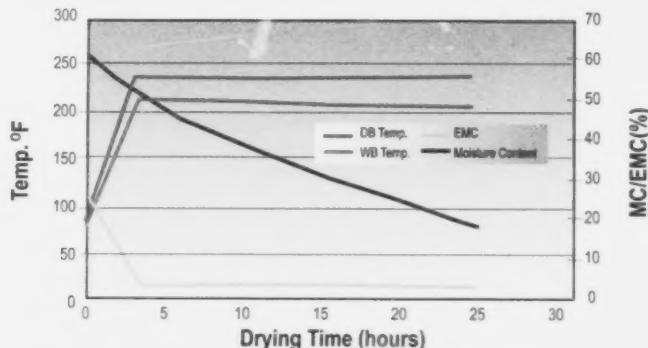
SCHEDULE H-2



Time (hrs)	2	7	10	End
Approx MC Range	30-29	29-24	24-20	20-16
Dry-Bulb	190	220	230	230
Wet-Bulb	160	175	180	180
EMC	6.0	3.7	3.3	3.3

Note: See Chapter 15 for information on selection and application of drying schedules.

SCHEDULE H-3



Time (hrs)	3	End
Approx MC Range	60-58	58-dry
Dry-Bulb	240	240
Wet-Bulb	210	200
EMC	4.9	3.9

GLOSSARY

This section provides brief definitions of terms generally used in lumber drying. Further detail on many of these terms can be found within the manual in the appropriate section(s). Free reference has been made to Forintek's previous kiln operator manuals and the U.S. Dry Kiln Operator's Manual.

ABSORPTION The taking-in or imbibing of water molecules (usually liquid form) at the surface of wood.

ADSORPTION The uptake of water molecules from the air directly into the wood. Adsorbed water is synonymous with bound water.

AIR VELOCITY The speed at which air moves, generally measured in feet per minute (fpm) or metres per second (m/s), on the exiting-air side of the lumber stack.

ANEMOMETER A mechanical or electronic instrument for measuring air velocity. A hot-wire anemometer is the preferred instrument for measuring airflow in a dry kiln.

ANNUAL RING The layer of growth added to the circumference of wood stems each year during the growing season; each ring includes earlywood (spring growth) and latewood (summer growth).

BAFFLE A piece of material (usually a metal or wood panel) used to block openings around the kiln load and deflect air through the sticker openings.

BOILER HORSEPOWER (BHP) Rating for energy output of boilers. One boiler horsepower is the energy required to evaporate 34.5 pounds (15.7 kg) of water per hour, from water at 212°F (100°C) to steam at the same temperature. This is equivalent to 33,475 BTU per hour (35.29 MJ/h).

BOUNDED WATER Water contained within the cell walls of wood and held by molecular association within the wood substance.

BRITISH THERMAL UNIT (BTU) The amount of heat necessary to increase the temperature of 1 pound of water by 1°F. (Its counterpart in the metric system is the joule (J) which is equivalent to 0.0009486 BTU.

BUNK (OR BOLSTER) A timber placed between stickered packages of lumber to provide for entry and exit of the forks of a lift truck.

CAMBIDIUM In wood anatomy, the one-cell-thick layer of tissue between the bark and wood that repeatedly subdivides to form new wood and bark cells.

CAPILLARY ACTION The combination of solid-liquid adhesion and surface tension by which a liquid is elevated in a tube or moves through a cellular structure.

CASEHARDENING (STRESS RELATED) A condition of stress and set in wood in which the outer fibres are under compressive stress and the inner fibres under tensile stress.

CASEHARDENING (MC RELATED) In softwood drying, casehardening is often used to describe a condition that exists later in drying where the surface has reached a very low MC but the core is still at an elevated MC.

CELL A general term for the minute units of wood structure, including wood fibres, vessel segments, and other elements of diverse structure and function. Each cell has a multi-layered wall enclosing a cavity (cell lumen).

CELLULOSE A long-chain carbohydrate molecule, the principal constituent of wood, forming the framework of the cells.

CHECK A drying defect, characterized by a separation between wood cells, extending into the wood, usually along the grain, and caused by tensile stresses induced as wood shrinks during drying. Checks may be further classified depending on their location; surface checks, end checks, and internal checks.

COIL, HEATING A heat exchanger made up of one or more runs of (usually) finned pipes through which steam, hot water, or hot oil flows to heat the circulated air.

COIL, RE-HEAT A supplementary heating coil, usually located between tracks of a double-track kiln, used to add heat to air that has already been cooled by moving through one portion of the load.

COLLAPSE A seasoning defect characterized by a corrugated or sunken appearance of the surface of a piece of dried wood; caused by an irregular drawing together of cell walls as free water leaves the cavities.

COMPRESSION WOOD Abnormal wood formed on the lower side of branches and inclined trunks of softwood trees. Compression wood is more dense and shrinks considerably more (especially in the longitudinal direction) than normal wood.

CONDITIONING A process for relieving the drying stresses in wood by subjecting the lumber, while in the kiln, to a relatively high humidity to increase the surface MC.

CROSS GRAIN In lumber – grain in which the fibre alignment deviates noticeably from the long axis of the wood member.

CROSS SECTION The face exposed when a cut is made across the grain of a board (at right angles to the fibres) – also called the transverse section.

CROSS SHAFT A fan-drive system in which the fan shaft is mounted parallel with the direction of air flow.

DEFECT, DRYING Any change in the condition or appearance of lumber which is the result of drying and which is detrimental to lumber quality, i.e., checks, splits, warp, stain, collapse, honeycombing.

DEGRADE, DRYING A drop in lumber grade that results from drying.

DENSITY (WOOD) Mass (weight) of wood per unit volume; usually expressed in pounds per cubic foot, grams per cubic centimetre, or kilograms per cubic metre.

DENSITY, BULK Mass (weight) of wood and water present per unit volume; usually expressed in pounds per cubic foot, grams per cubic centimetre, or kilograms per cubic metre.

DEPRESSION, WET-BULB The difference between the dry- and wet-bulb temperatures.

DESUPERHEATER A device for removing from steam the heat in excess of that required for saturation at a given pressure. In kiln drying, atomized water injection is often used to eliminate the superheat from the steam employed for humidification.

DIFFUSION Spontaneous movement of heat, moisture, or gas throughout a body or space. Movement is from high points to low points of temperature or concentration.

DIRECT-FIRED A method of heating a dry kiln where the hot gases produced by burning gas, oil, or wood byproducts are discharged directly into the kiln atmosphere.

DRY-BULB A “bare” temperature sensor exposed to an air stream to measure the dry-bulb temperature.

DRY-BULB TEMPERATURE The temperature of the air as determined by a “bare” thermometer or thermocouple.

DRYING RATE The amount of moisture lost from lumber per unit of time; generally expressed in moisture content (%) loss per hour or per day.

DRYING SCHEDULE A series of predefined steps that determine how the various control parameters of a kiln will be regulated to achieve a specific drying rate and final moisture content. In a heat-and-vent (conventional) kiln this will typically be a series of dry- and wet-bulb temperatures expressed as a function of time (time-based schedule) or wood moisture content (MC-based schedule).

EARLYWOOD That portion of the annual growth ring produced at the beginning or early in the growing season – also called springwood. Earlywood is typically lighter in colour than latewood.

EDGE-GRAIN The grain produced when a board is sawn so that the annual growth rings are mainly perpendicular to the flat face of the board – also called vertical grain and quarter-sawn.

EQUALIZATION (in kiln drying) A process for reducing within and between board variation in final moisture content of lumber after normal drying is complete.

EQUILIBRIUM MOISTURE CONTENT (EMC) Moisture content at which wood neither gains nor loses moisture when surrounded by air at a given (and constant) relative humidity and dry-bulb temperature. The moisture content which wood eventually attains when subjected to any given constant condition of humidity and temperature.

EXTRACTIVES Chemical constituents of wood that are not an integral part of the cellular structure and that can be removed by a solvent such as water or benzene.

FIBRE OR FIBRE TRACHEID Long, thin, cylindrical wood cells, tapered and closed at both ends. Also a general term of convenience for any long, narrow cellular tissue, i.e., fibrous.

FIBRE SATURATION POINT (FSP) The stage in the drying or wetting of wood at which the cell walls are saturated with water and the cell cavities are free of liquid water. It is usually assumed to be approximately 30% moisture content (MC). The FSP varies (usually downward) from 30% MC according to the species and other factors. It is significant in drying since any changes in MC below the FSP will result in either shrinkage (moisture loss) or swelling (moisture regain) of the wood.

FLAT-GRAIN The grain or figure produced when a board is sawn so that the annual growth rings are mainly parallel to the flat face of the board – also called flat-sawn or plain-sawn.

HEARTWOOD The wood extending from the pith (centre of the tree) outward to the sapwood. It is generally darker than the sapwood due to the formation of gums, resins and other substances which accumulate when the cells die.

HEAT EXCHANGER A device designed to introduce heat into a process, for example finned pipe carrying steam or hot water from a central boiler. Also, a device to transfer heat from one part of a process to another, for example a plate-type heat exchanger to recapture heat from exhaust air and pre-heat the incoming air.

HEAT TREATMENT (PHYTOSANITARY) Heating wood to achieve a specific temperature known to be lethal to wood inhabiting pests (insects, nematodes) or as defined by various regulatory agencies for access to foreign markets.

HIGH-TEMPERATURE DRYING Drying systems or schedules that employ dry-bulb temperatures in excess of 212°F (100°C).

HONEYCOMBING A drying defect characterized by a separation of the fibres in the interior of the piece, usually along the wood rays (in the radial direction). The failures are not usually visible on the surface, although they may be extensions of surface and end checks.

HUMIDITY, ABSOLUTE The actual weight of water (vapour) per unit weight of dry air, independent of air temperature and pressure.

HUMIDITY, RELATIVE The ratio of the actual vapour pressure to the pressure of saturated vapour at the prevailing dry-bulb temperature. In a practical sense it is an expression of the amount of water vapour present in air in comparison with the theoretical maximum at the same conditions of dry-bulb temperature and pressure.

HYGROMETER An instrument for measuring the relative humidity of air.

HYGROSCOPICITY The property of a substance such as wood, which permits it to absorb or lose moisture readily.

INDIRECT-FIRED A kiln that is heated by a central burner system producing steam, hot water, or hot oil which is circulated within the kiln and the heat transferred to the kiln air via a radiating surface such as finned pipes.

JOULE (J) Metric measure of heat or energy. One Joule is equivalent to 0.0009486 BTU.

JUVENILE WOOD Wood adjacent to the pith of the tree and formed during the first few years of growth. These annual rings are generally wider and the wood of a lower density than normal wood. This wood also tends to shrink more (especially longitudinally) than normal wood.

KILN An enclosed chamber in which the environmental conditions are controlled to achieve drying, equalizing, or conditioning of lumber.

KILN, DEHUMIDIFICATION A dry kiln that operates in a closed system employing a heat pump to dehumidify the kiln air and extract the latent heat to recirculate to the kiln in the form of sensible heat to maintain or raise the dry-bulb temperature.

KILN, PROGRESSIVE A kiln in which the lumber is either continuously or intermittently moved (usually in stickered packages) to expose it to different environmental conditions to achieve drying and or equalization and conditioning.

KILN, VACUUM A dry kiln equipped with an airtight chamber and vacuum pump to dry wood at sub-atmospheric pressures.

LATENT HEAT Heat which, when added to or abstracted from a substance, does not affect its temperature but does change its state. For example, heat is required to change water at 212°F (100°C) to steam at 212°F (100°C).

LATEWOOD That portion of the annual growth ring that is formed during the latter part of the growing season – also called summerwood. This part of the growth ring is typically darker in colour and has higher density than earlywood (springwood).

LIGNIN A substance of the wood cell wall which acts as a binding agent to hold cells and cell wall components together.

LINE SHAFT A fan-drive system in which multiple fans are linked via one or more long shafts that run perpendicular to the direction of air flow.

METER, MOISTURE An instrument for determining the moisture content of wood. Most commercial moisture meters for dry wood are based on the relationship of a particular electrical property that varies in a predictable way with the wood moisture content.

METER, IN-LINE An instrument installed along a production line (sawmill or planer mill) to measure the moisture content of individual boards. These instruments are based on either an electrical (i.e., DC-resistance) or physical (i.e., weight) property that can be related to the moisture content of the wood.

MICROFIBRIL Bundles of cellulose polymer chains that make up the cell wall. The orientation of microfibrils will affect the shrinkage and swelling properties of wood.

MOISTURE CONTENT (MC) In wood, the weight of water (bound and free) present, expressed as a percentage of the oven-dry weight of the wood.

MOISTURE GRADIENT A variation in moisture content usually considered across the thickness of a board. A normal, post-drying moisture gradient will vary from a low MC at the surface to a high MC in the core. A reverse moisture gradient may develop in boards that have been dried and subsequently re-wetted.

PIT A minute opening in the cell wall of woody cells, providing a passageway from one cell lumen (cavity) to the next. The condition (openness) of pit openings has a significant impact on drying rate.

PLENUM In a kiln the space provided on the air entering or exiting side of the load between the load and the kiln wall. This space acts as a pressure zone and reservoir on the entering side of the load to achieve uniform airflow from top to bottom and along the length of the kiln.

PRE-SORTING Sorting lumber before drying on the basis of a physical property, such as MC or density, that has been shown to have a direct correlation with drying time.

PSYCHROMETER An instrument for measuring the dry-bulb and wet-bulb temperatures of the air, usually consisting of two thermometers. The difference between the two thermometers (the wet-bulb depression) is used to determine the relative humidity of the air and the equilibrium moisture content (EMC) for wood (from standard tables).

RADIO FREQUENCY (RF) Oscillating frequency (cycles per second or Hertz) of an electric field with frequencies of 10 kilohertz and higher.

RAY, WOOD In wood anatomy a band of wood cells extending radially from the pith towards the bark.

REACTION WOOD Wood of more or less distinctive anatomical and shrinkage characteristics, formed in parts of leaning or crooked stems. In hardwoods it is termed "tension wood" and in softwoods "compression wood".

RECORDER-CONTROLLER Instrumentation which automatically controls the kiln environmental conditions and records the information for future reference.

RE-DRYING A process in which boards exceeding a pre-defined upper limit after an initial kiln drying treatment are identified, removed, and returned to a kiln for further drying.

REFRACTORY WOOD In relation to drying – wood that is difficult to dry. It is relatively impermeable to the movement of liquids, for example, wet pockets in balsam or subalpine fir.

RESIN CANAL OR RESIN DUCT A tubular intercellular space usually containing resin and sheathed with specialized cells which secrete resin when in the living sapwood.

RTD (RESISTANCE TEMPERATURE DETECTOR) Electronic temperature sensor based on the change in electrical resistance with changing temperature.

SAMPLE BOARD A board, or portion of a board, placed within the kiln load for the specific purpose of monitoring the drying rate. The board may be removed periodically for weighing or may be fitted with a probe(s) to electrically measure the MC.

SAPWOOD The outer portion of a wood stem that, in a living tree, contains living cells and reserve materials. The sapwood is usually lighter in colour than heartwood and, in the case of softwoods, has a considerably higher green moisture content.

SENSIBLE HEAT Heat which, when added to or abstracted from a substance, changes its temperature (see Latent Heat).

SET In relation to lumber seasoning, a localized semi-permanent deformation in wood caused by internal stresses. Wood may become set due to compressive (compression set) or tensile (tension set) forces.

SHAKE As seen on the end grain, shake is a separation of wood fibres parallel to the annual rings. Shake may be the result of physical conditions that the tree was exposed to while growing but in softwoods is more often associated with wetwood in those species susceptible to this defect.

SHELL In lumber, the outer portion of sawn boards and timbers.

SHRINKAGE Contraction which occurs as wood is dried below the fibre saturation point.

SPECIFIC GRAVITY (BASIC) The ratio of the oven-dry weight of a piece of wood to the weight of water at 39 F (4 C) displaced by the wood. It is based on the green volume of the wood.

SPF (SPRUCE-PINE-FIR) Species grouping as defined by the National Lumber Grades Authority (NLGA) which identifies 8 Canadian species falling within this grouping (See Chapter 1).

STAIN, BLUE-STAIN A bluish or grayish discoloration in the sapwood caused by the growth and presence of certain dark-coloured fungi on the surface and in the interior of the wood.

STAIN, BROWN A brownish discoloration of chemical origin in wood that sometimes occurs during the air drying or kiln drying of several softwood species (particularly white pine).

STAIN, STICKER A discoloration in wood in the zone of contact with the sticker that can be due to fungal or chemical action as a result of the slow drying conditions that sometimes exist there.

STEAM, SATURATED Steam at the same temperature as the water from which it was formed (and which does not contain droplets of water), as distinct from steam which has been subsequently heated.

STEAM, SUPERHEATED Steam at a temperature higher than the saturation temperature at a given pressure.

STEAM, WET Steam which contains suspended droplets of water.

STEAM TRAP A mechanical device used on a steam line to automatically expel condensed water, while at the same time preventing the passage of steam.

STICKERS Strips or slats used to separate the layers (tiers) of lumber in a stack, thereby permitting air to circulate between the layers.

STRESS, DRYING Stress that occurs in wood during drying because of moisture gradients and its inherent tendency to shrink unevenly and to develop a "set" condition. Re-sawing or otherwise machining material with drying stress may result in deformations such as cupping.

STRESS RELIEF The result of a conditioning treatment following the final stages of drying, which causes a redistribution of moisture and relief of set, with a consequent relief of stresses.

STRESS SECTION A cross section of a board that is cut into prongs of equal thickness from face to face, to detect the presence of stresses in wood.

TEMPERATURE DROP ACROSS THE LOAD (TDAL) The reduction in dry-bulb temperature as air passes through a load of lumber and sensible heat is abstracted from the air to achieve heating and drying of the lumber.

THERMOCOUPLE A temperature sensing device consisting of a pair of wires made of dissimilar metals, fused at one end and that generate a voltage signal proportional to the temperature at the point the wires are fused.

TOP RESTRAINT A mechanical restraining system or weights placed on top of the kiln load to apply physical restraint to the lumber during drying in an effort to reduce warp.

TRACHEID The long, cylindrical, fibrous cells which constitute a major part of the cellular structure of softwood trees.

WARP A general term to describe various distortions (deviations from a straight and flat condition) that develop as a result of drying or growth stresses, or that may have been machined into the wood. (See also bow, crook, cup and twist in Chapter 17.)

WET-BULB A temperature sensing bulb which is covered by an absorbent wick extending into a water reservoir.

WET-BULB TEMPERATURE The temperature indicated by a thermometer where the sensing portion is covered by a wick, wetted with water, and exposed to air movement. The resulting evaporation cools the water and the sensing portion of the thermometer to the wet-bulb temperature.

WETWOOD OR WET POCKETS Zones within wood having some or all of the following characteristics: high moisture content, presence of bacteria, more acidic than adjacent wood, and lower permeability than normal wood.

FURTHER READING

This manual is in part the result of experiences gained from research conducted at Forintek on the drying of SPF lumber. The following is a list of research reports that readers may wish to review if looking for further detailed information on specific topics.

FPINNOVATIONS – FORINTEK REPORTS

(for information on obtaining copies of these reports please contact the FPInnovations – Forintek library at either the Vancouver or Quebec laboratories – see inside back cover for contact information).

REVIEW OF INDUSTRIAL SORTING TECHNOLOGIES FOR GREEN LUMBER

Oliveira, L. 2003. Report prepared for Coastal Forest and Lumber Association. Contract No. 2003-3824.

OPPORTUNITIES TO REDUCE ENERGY CONSUMPTION IN LUMBER DRYING

Elustondo, D., L. Oliveira, and J. Wallace. 2005. Forintek general revenue project No. 4400.

ECONOMIC IMPACT OF STICKER SPACING ON THE QUALITY OF KILN-DRIED SOFTWOOD CONSTRUCTION LUMBER

Normand, D. and M. Savard. Forintek general revenue project No. 4031.

SORTING AND DRYING EASTERN SPF ON THE BASIS OF INITIAL MOISTURE CONTENT

Garrahan, P.A., M. Savard, and D.A. Cane. 1994. Forintek project No. 3743K441.

ANALYSIS OF DEGRADE LEVELS IN DRYING EASTERN SPRUCE-PINE-FIR DIMENSION LUMBER

Garrahan, P. and D. Cane. 1988. Forintek project No. 3743K411.

TECHNICAL AND ECONOMIC EVALUATION OF TOP RESTRAINT TO REDUCE DEGRADE LOSSES IN EASTERN SPRUCE-PINE-FIR

Garrahan, P.A. 1997. Forintek project No. 3742K428.

EVALUATION OF FACTORS INFLUENCING ACCURACY OF MOISTURE CONTENT ESTIMATES WITH A DIELECTRIC MOISTURE METER

Garrahan, P. and V. Lavoie. 2004. Forintek general revenue project No. 1941.

IMPACT OF AIRFLOW ON THE DRYING RATE OF BLACK SPRUCE

Normand, D. and V. Lavoie. 2005. Forintek general revenue project No. 4033.

DRYING SUBALPINE FIR WITH WET POCKETS

Hartley, I.D. 1997. Forintek report prepared for the Canadian Forest Service, project No. 1003 (CFS No. 36).

EQUALIZING AND CONDITIONING OF SPF DIMENSION LUMBER

Cai, L. and L. Oliveira. 2001. Forintek project No. 2347.

THE CAUSES AND OCCURRENCE OF WARP IN EASTERN SPRUCE-PINE-FIR DIMENSION LUMBER

Barbour, R.J. and G. Chauret. 1993. Forintek report No. 3712K209.

PHYSICAL PROPERTIES RELATED TO DRYING TIME OF EASTERN SPF

Savard, M. 1995. Forintek project No. 3712K220.

METHOD TO EVALUATE THE BEHAVIOUR OF FROZEN LUMBER DURING THE PREHEATING PHASE

Léger, F. 2001. Forintek project No. 2673.

DRYING AND PRE-DRYING OF BALSAM FIR IN AN AIR DRYING YARD (REPORT AVAILABLE IN FRENCH ONLY)

Tremblay, C. 2003. Forintek report No. 3259.

DRYING RATES OF SPF (WESTERN) LUMBER

Oliveira, L.C. 1995. Forintek report prepared for the Canadian Forest Service, project No. 1212K039 (CFS No.30).

OTHER PUBLICATIONS (NON FORINTEK)

DRY KILN OPERATOR'S MANUAL

Simpson, W.T. 1991. United States Department of Agriculture, Forest Service, Forest Products Laboratory. Agriculture Handbook 188. (Available through the Forest Products Society, Madison, WI.)

DRY KILN SCHEDULES FOR COMMERCIAL WOODS – TEMPERATE AND TROPICAL

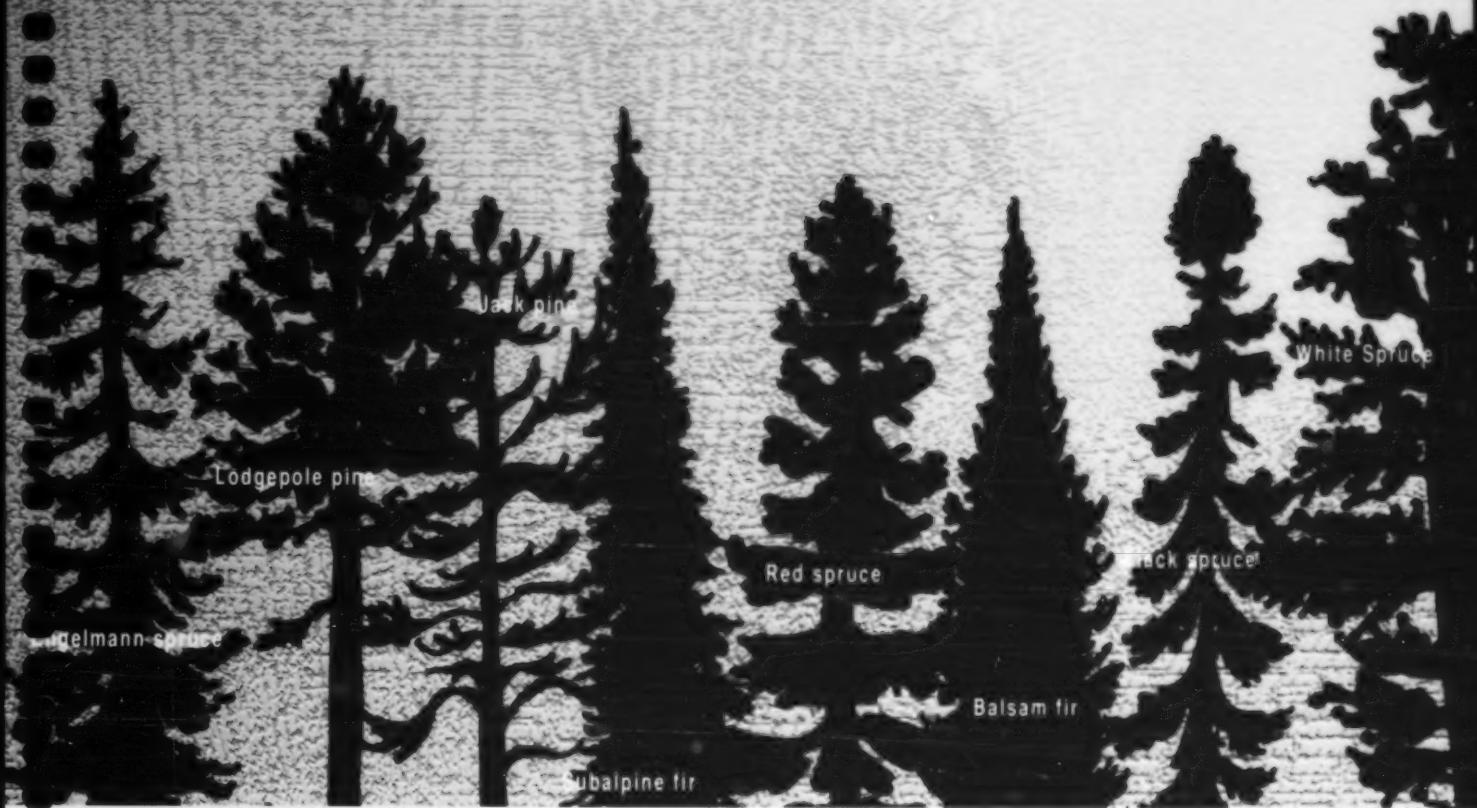
Boone, R.S., C.J. Kozlik, P.J. Bois, and E.M. Wengert. 1993. United States Department of Agriculture, Forest Service, Forest Products Laboratory. (Available through the Forest Products Society, Madison, WI.)
ISBN 0-935018-60-3.

SOFTWOOD DRYING – ENHANCING KILN OPERATIONS

Culpepper, L. 2000. Published by Miller Freeman Books, San Francisco. ISBN 0-87930-581-9.

HIGH TEMPERATURE DRYING – ENHANCING KILN OPERATIONS

Culpepper, L. 1990. Published by Miller Freeman Books, San Francisco. ISBN 0-87930-186-4.



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Successful drying is the result of paying
attention to many small, seemingly
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